A 56-year-old man comes to the office due to chronic cough and fatigue. The patient has smoked 2 packs of cigarettes daily since age 18. Physical examination shows cyanosis and expiratory wheezes scattered throughout the lungs. During evaluation for long-term oxygen therapy, his respiratory rate decreases shortly after he begins nasal cannular oxygen supplementation. This patient's reduced respiratory rate is most likely caused by a sudden decrease in stimulation of which of the following sensory receptors?

A. Carotid bodies

B. Central chemoreceptors

C. Juxtaglomerular apparatus

D. Pulmonary C fibers

E. Pulmonary stretch receptors

Submit

A 56-year-old man comes to the office due to chronic cough and fatigue. The patient has smoked 2 packs of cigarettes daily since age 18. Physical examination shows cyanosis and expiratory wheezes scattered throughout the lungs. During evaluation for long-term oxygen therapy, his respiratory rate decreases shortly after he begins nasal cannular oxygen supplementation. This patient's reduced respiratory rate is most likely caused by a sudden decrease in stimulation of which of the following sensory receptors?

- ✓ A. Carotid bodies (39%)
- B. Central chemoreceptors (50%)
- C. Juxtaglomerular apparatus (0%)
- D. Pulmonary C fibers (2%)
- E. Pulmonary stretch receptors (7%)

Omitted
Correct answer
A

39%
Answered correctly

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02/14/2020
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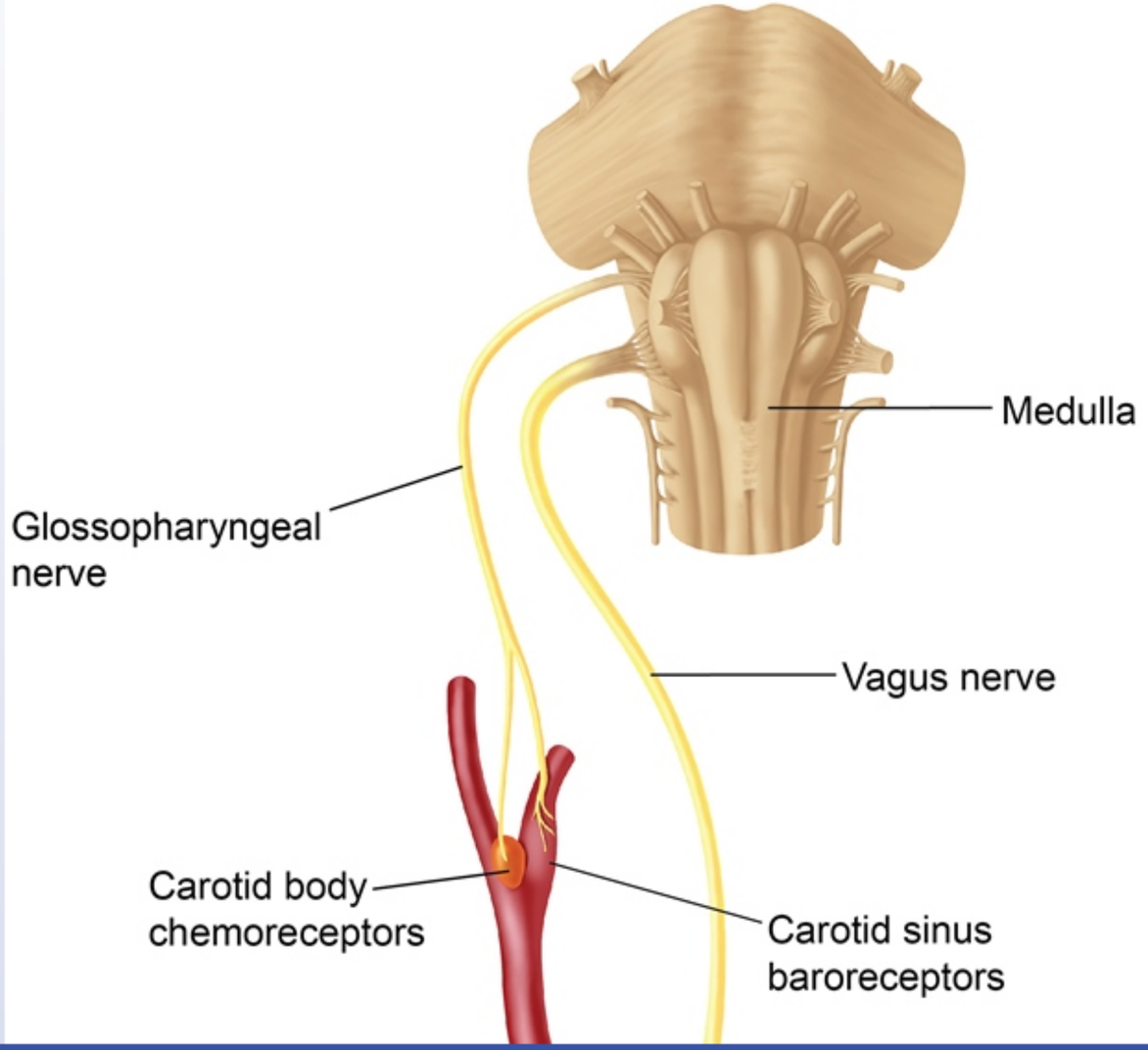
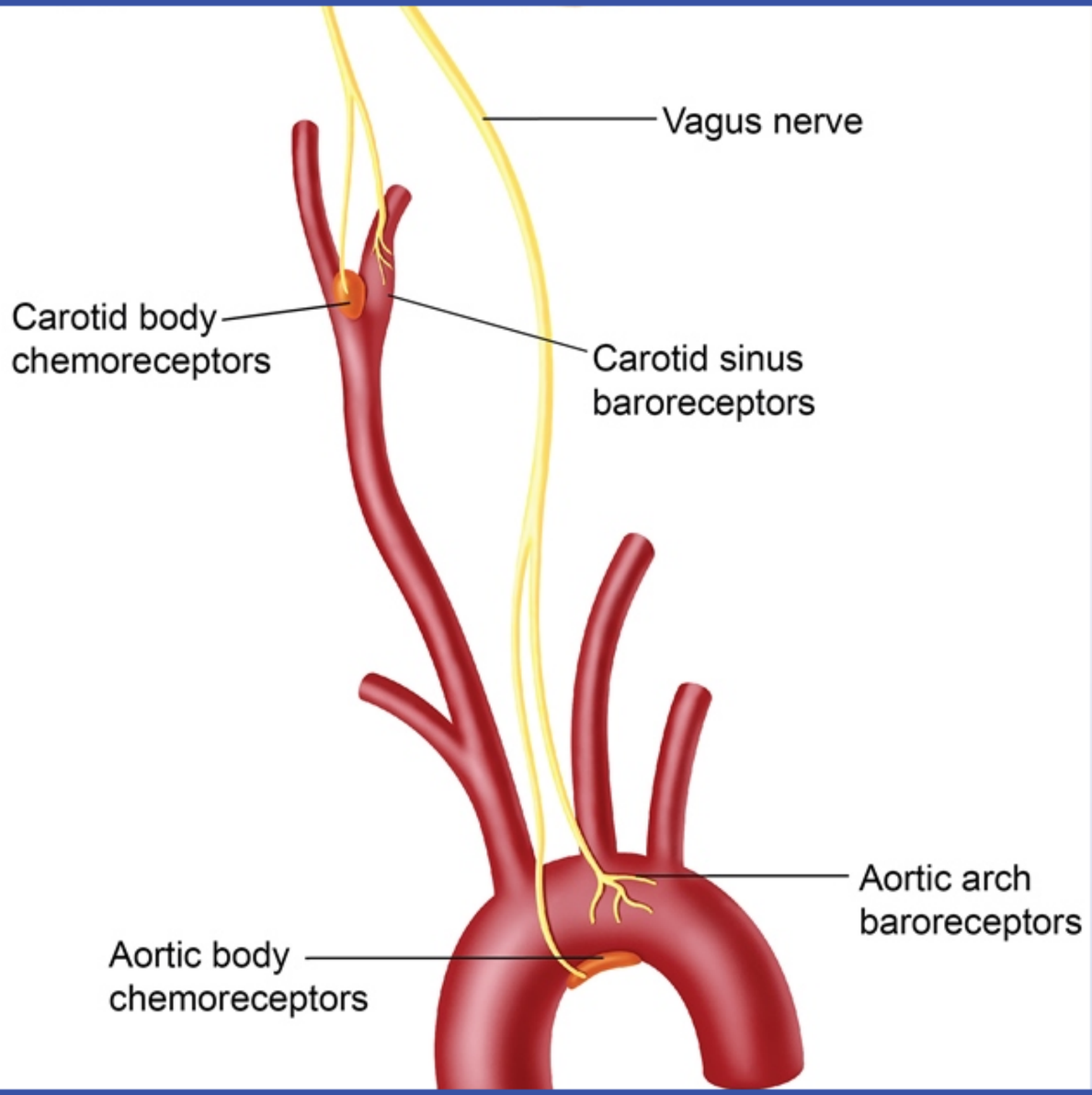
Explanation

Baroreceptors & peripheral chemoreceptors

Baroreceptors & peripheral chemoreceptors



nerve


Vagus nerve
Carotid body chemoreceptors
Carotid sinus baroreceptors
Aortic arch baroreceptors
Aortic body chemoreceptors

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This patient with **chronic obstructive pulmonary disease** (COPD) developed a **decrease in respiratory rate** as a result of oxygen supplementation. Oxygen has a minimal effect on respiratory drive unless the arterial partial pressure of oxygen (PaO_2) drops below 60-70 mm Hg; therefore, the arterial partial pressure of carbon dioxide ($PaCO_2$) is the major stimulator of respiration in healthy individuals. However, patients with long-standing COPD have decreased sensitivity to $PaCO_2$ (due to chronic CO_2 retention) and may also have profound hypoxemia (PaO_2 <60 mm Hg); therefore, PaO_2 levels can become a significant contributor to respiratory drive.

The depth and rate of respirations are controlled by the medullary respiratory center based on input from central and peripheral chemoreceptors and airway mechanoreceptors. Peripheral chemoreceptors found in the **carotid and aortic bodies** are the primary sites for sensing PaO_2 and are stimulated by hypoxemia. When **supplemental oxygen** is administered, the rapid increase in PaO_2 can **reduce peripheral chemoreceptor stimulation** and decrease the respiratory rate.

Reduced respiratory rate is a minor contributor to the oxygen-induced hypercapnia that can occur in patients with COPD; increased ventilation-perfusion mismatch triggered by alleviation of pulmonary vasoconstriction in poorly ventilated areas is the major mechanism.

(Choice B) Central chemoreceptors, located in the medulla, are more involved in the respiratory response to hypercapnia than to hypoxemia. CO_2 readily diffuses through the blood-brain barrier and forms hydrogen ions in the cerebrospinal fluid; the resulting decrease in pH is detected by medullary neurons, triggering an increase in respiration. Because the blood-brain barrier is relatively impermeable to hydrogen ions, blood pH itself has little effect on central chemoreceptors.

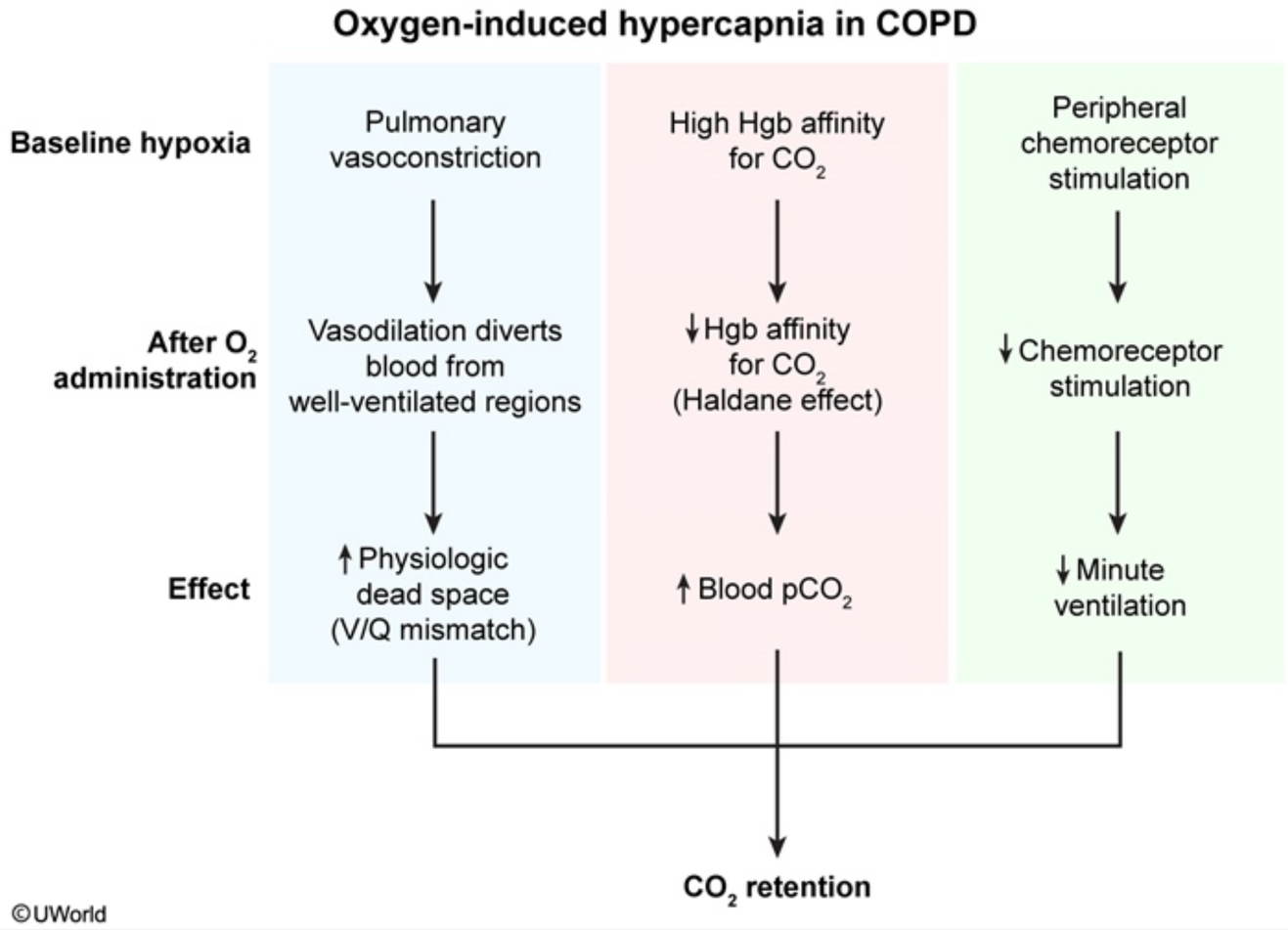
(Choice C) The juxtaglomerular apparatus is located in the kidneys and consists of juxtaglomerular cells and the macula densa. It helps regulate renal blood flow and the glomerular filtration rate via renin secretion.

(Choices D and E) Pulmonary stretch receptors include myelinated and unmyelinated C fibers in the lungs and airways. These receptors regulate the duration of inspiration depending on the degree of lung distension (Hering-Breuer reflex).

Educational objective:
Arterial partial pressure of carbon dioxide ($PaCO_2$) is the major stimulator of respiration in healthy individuals; even a slight increase in $PaCO_2$ stimulates central chemoreceptors and triggers increased ventilation. In patients with chronic obstructive pulmonary disease, the response to

supplementation. Oxygen has a minimal effect on respiratory drive unless the arterial partial pressure of oxygen (PaO_2) drops below 60-70 mm

Exhibit Display



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The depth and rate of respirations are controlled by the medullary respiratory center based on input from central and peripheral chemoreceptors and airway mechanoreceptors. Peripheral chemoreceptors found in the **carotid and aortic bodies** are the primary sites for sensing PaO_2 and are stimulated by hypoxemia. When **supplemental oxygen** is administered, the rapid increase in PaO_2 can **reduce peripheral chemoreceptor stimulation** and decrease the respiratory rate.

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Educational objective:
Arterial partial pressure of carbon dioxide ($PaCO_2$) is the major stimulator of respiration in healthy individuals; even a slight increase in $PaCO_2$ stimulates central chemoreceptors and triggers increased ventilation. In patients with chronic obstructive pulmonary disease, the response to $PaCO_2$ is blunted and hypoxemia can contribute to respiratory drive. Peripheral chemoreceptors are primarily responsible for sensing arterial partial pressure of oxygen (PaO_2) and can be suppressed with oxygen administration.

Physiology	Pulmonary & Critical Care	COPD
Subject	System	Topic

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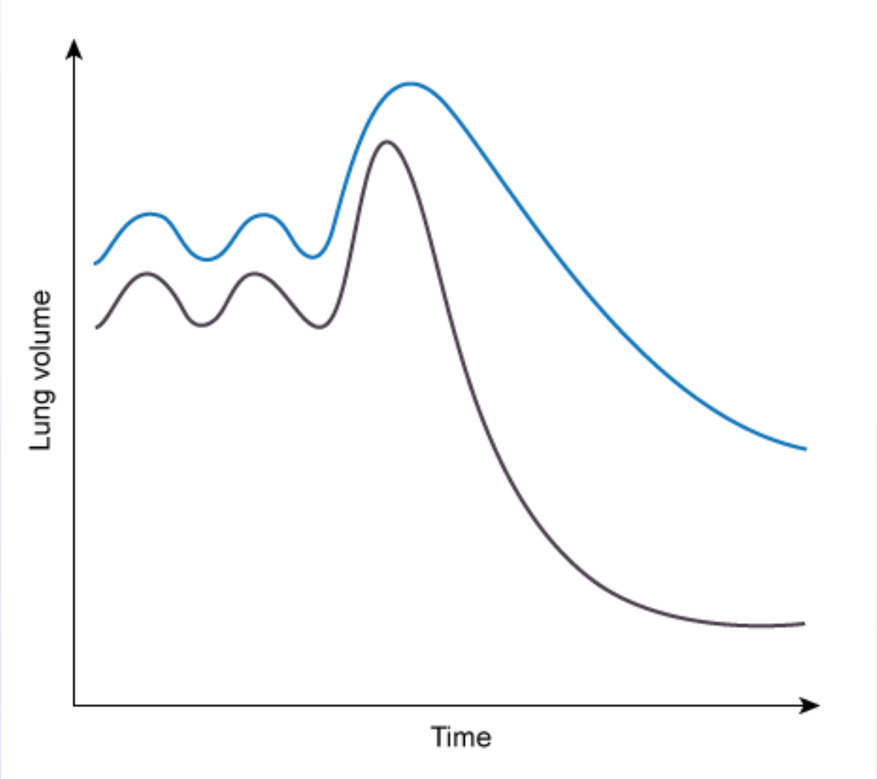
A 34-year-old man is evaluated due to dyspnea. The patient undergoes complete pulmonary function testing as well as lung volume measurements. His pulmonary volume curve (blue line) is compared with a normal individual's curve (black line) in the illustration below:

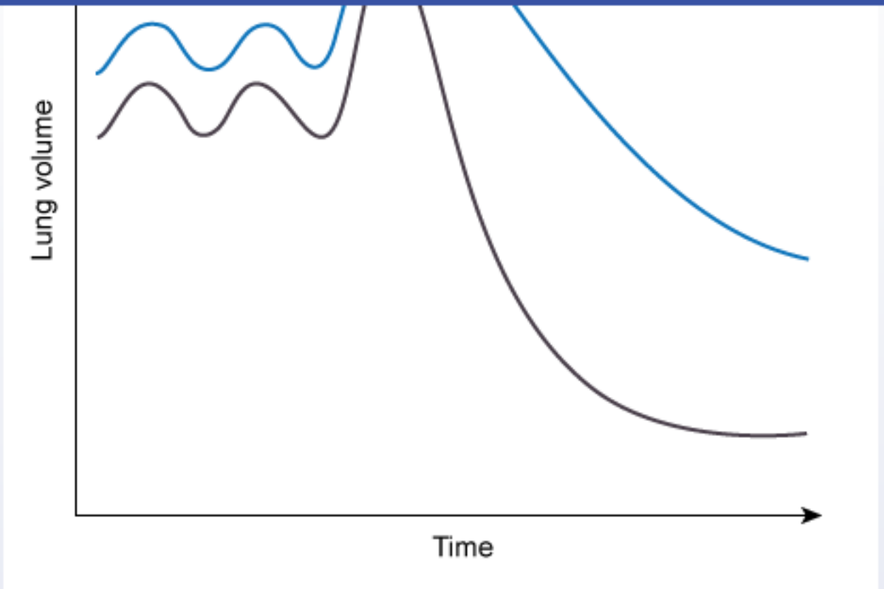


Which of the following measures is increased in this patient?

A. Expiratory reserve volume

B. Forced expiratory volume in 1 second

C. Forced expiratory volume in 1 second/forced vital capacity ratio



Which of the following measures is increased in this patient?

- A. Expiratory reserve volume
- B. Forced expiratory volume in 1 second
- C. Forced expiratory volume in 1 second/forced vital capacity ratio
- D. Forced vital capacity
- E. Residual volume/total lung capacity ratio

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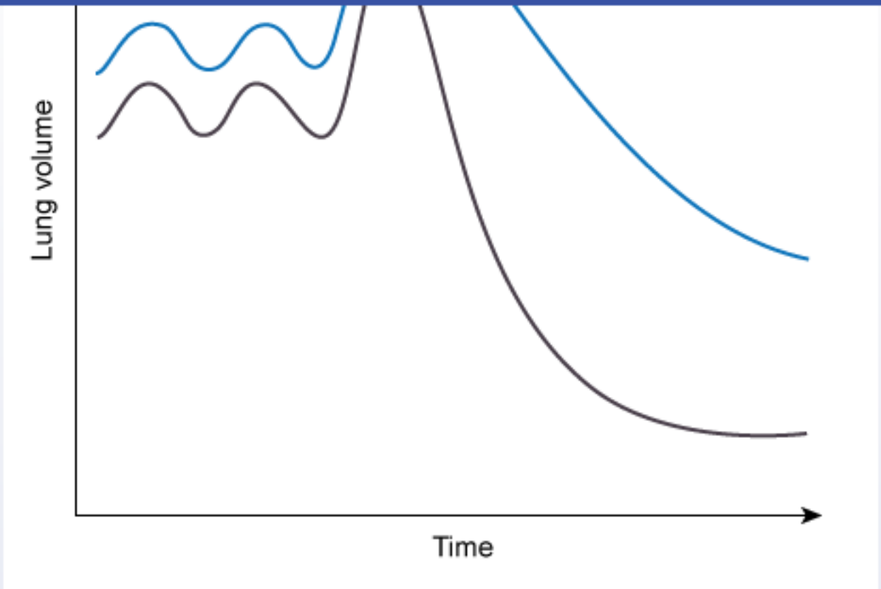

Which of the following measures is increased in this patient?

A. Expiratory reserve volume (17%)

B. Forced expiratory volume in 1 second (4%)

C. Forced expiratory volume in 1 second/forced vital capacity ratio (9%)

D. Forced vital capacity (6%)

✓ E. Residual volume/total lung capacity ratio (62%)

Omitted
Correct answer

62%
Answered correctly

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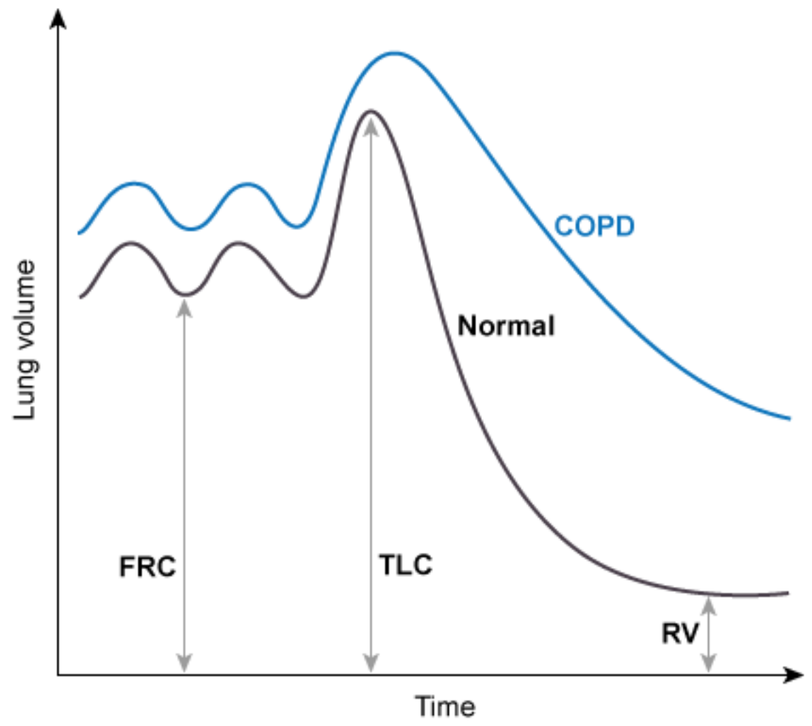
Explanation



COPD = chronic obstructive pulmonary disease; **FRC** = functional residual capacity; **RV** = residual volume; **TLC** = total lung capacity.

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The graph compares the respiration curve for a normal, healthy individual (black line) and this patient (blue line), who has **chronic obstructive pulmonary disease** (COPD); the tracings show resting breaths along with a maximal air intake and expulsion effort. In a resting breath, a single tidal volume (TV) is exchanged. With maximal inhalation, the curve includes both the TV and the inspiratory reserve volume (IRV), which together

COPD = chronic obstructive pulmonary disease; **FRC** = functional residual capacity; **RV** = residual volume; **TLC** = total lung capacity.
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The graph compares the respiration curve for a normal, healthy individual (black line) and this patient (blue line), who has **chronic obstructive pulmonary disease** (COPD); the tracings show resting breaths along with a maximal air intake and expulsion effort. In a resting breath, a single tidal volume (TV) is exchanged. With maximal inhalation, the curve includes both the TV and the inspiratory reserve volume (IRV), which together equal the inspiratory capacity. With maximal exhalation, the curve reflects the expulsion of the IRV and the TV, as well as the amount of additional air that can be expired, which is the expiratory reserve volume (ERV). The air remaining in the lungs following full exhalation is the residual volume (RV).

COPD causes air trapping and hyperinflation of the lungs, so these patients breathe at higher baseline lung volumes (**higher FRC**). The absolute volume of air in the lungs that is not respired, the **RV**, is substantially **increased**. The **total lung capacity** (TLC) also **increases** but to a lesser extent than RV. Therefore, the fraction of air in the lungs that is not involved in respiration, the **RV/TLC ratio**, is also **increased**.

(Choice A) ERV is decreased in obstructive lung disease, as less air can be forcefully exhaled due to obstruction. The substantial increase in RV is greater than the decrease in ERV, resulting in the overall increase in FRC.

(Choices B, C, and D) Both forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV1) are decreased in obstructive lung disease due to airway obstruction. Because FEV1 is decreased more than FVC, the FEV1/FVC ratio is also decreased (<0.7 in COPD).

Educational objective:
Chronic obstructive pulmonary disease causes air trapping and hyperinflation; consequently, these patients breathe at higher baseline lung volumes (higher functional residual capacity). The absolute volume of air in the lungs that is not respired (residual volume) increases substantially, as does the fraction of air in the lungs that is not involved in respiration (residual volume/total lung capacity ratio).

Physiology	Pulmonary & Critical Care	COPD
Subject	System	Topic

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COPD = chronic obstructive pulmonary disease; FRC = functional residual capacity;

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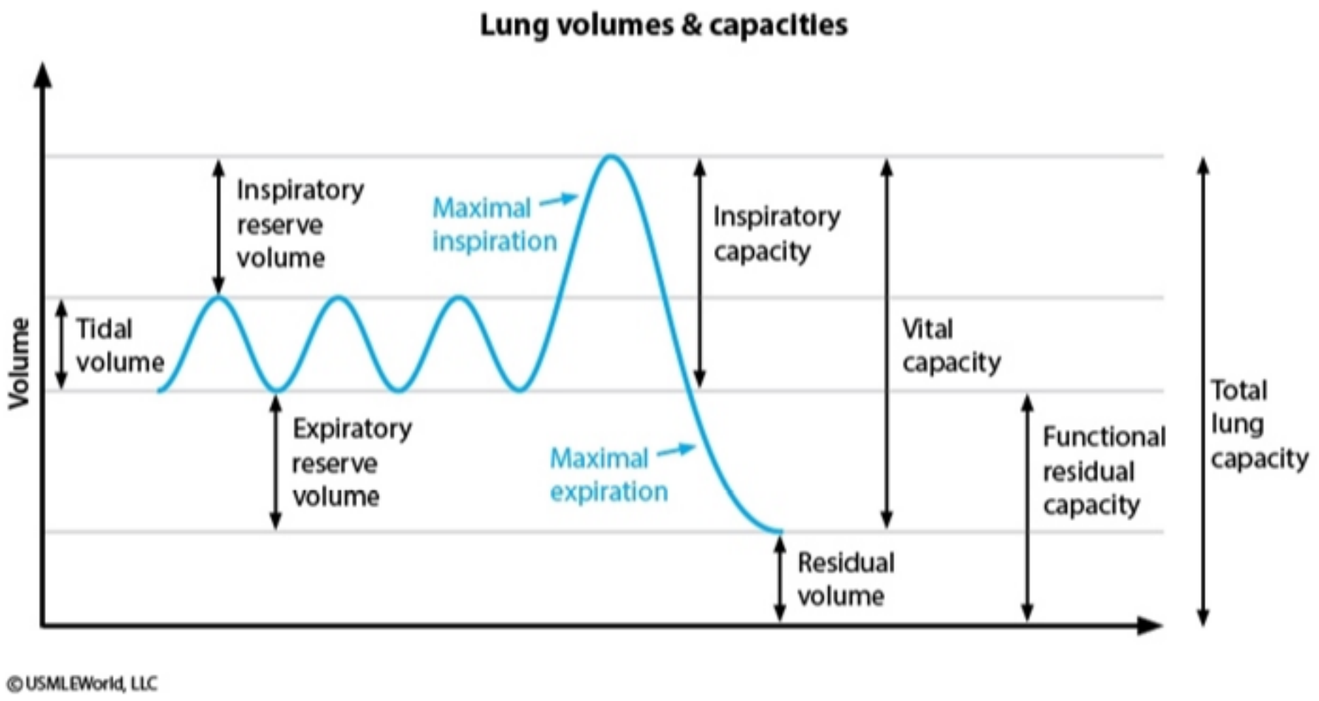

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COPD = chronic obstructive pulmonary disease; FRC = functional residual capacity;

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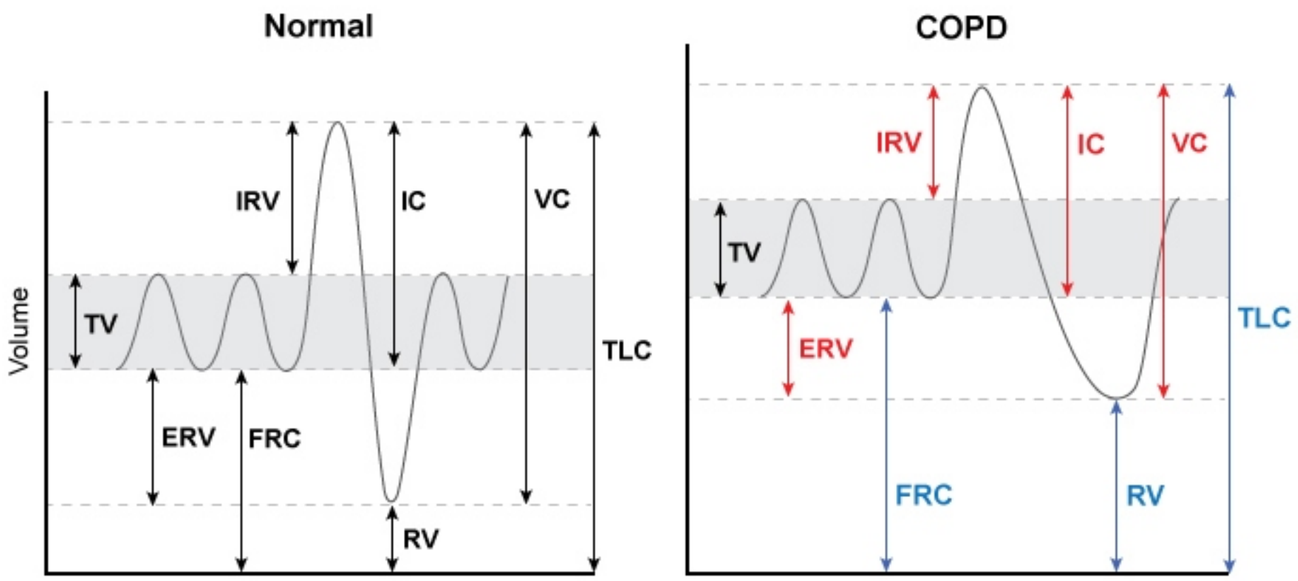

COPD = chronic obstructive pulmonary disease; **ERV** = expiratory reserve volume; **IC** = inspiratory capacity; **IRV** = inspiratory reserve volume; **FRC** = functional residual capacity; **RV** = residual volume; **TLC** = total lung capacity; **TV** = tidal volume; **VC** = vital capacity.

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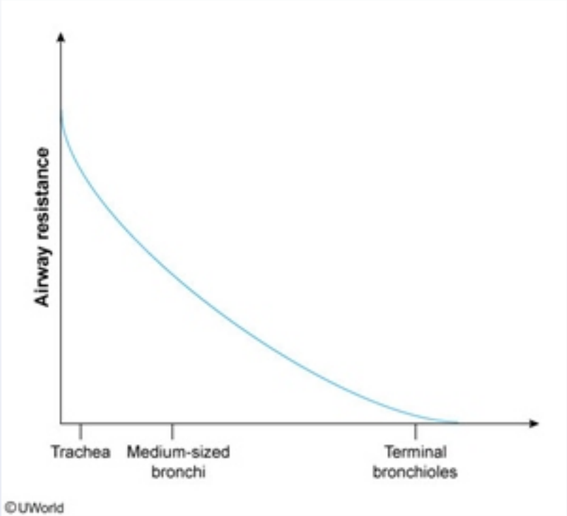
Respiratory physiologists conduct a study to assess the airway resistance of the lower respiratory tract in healthy volunteers. During the experiment, they measure total cross sectional airflow resistance as it changes between each airway generation. Which of the following graphs is most likely to be observed in this study?

A.



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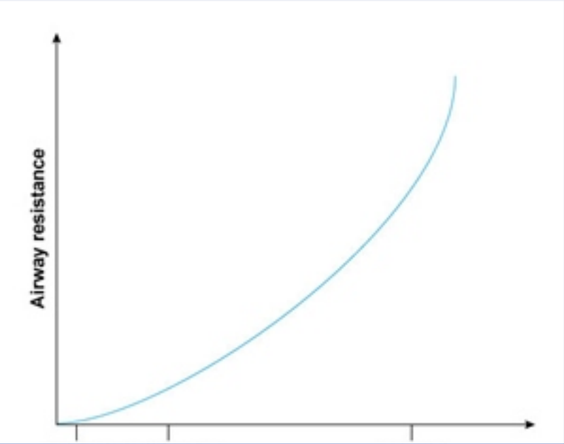

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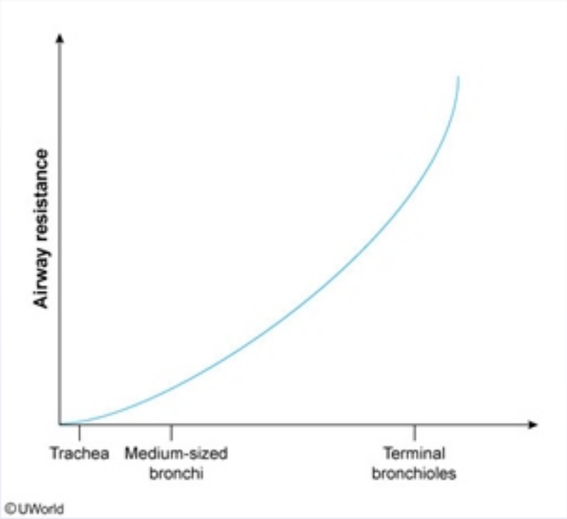

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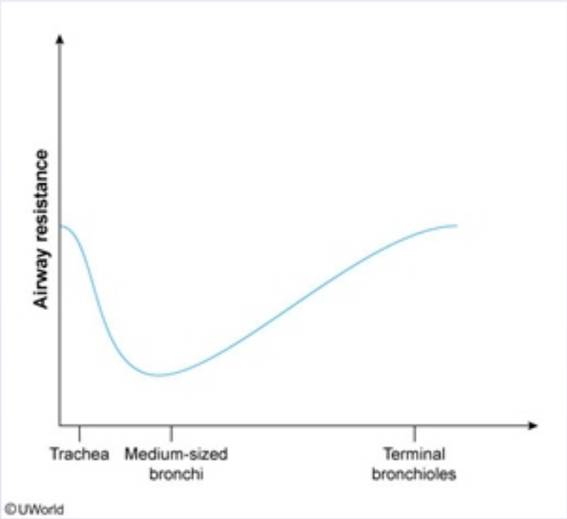

D.

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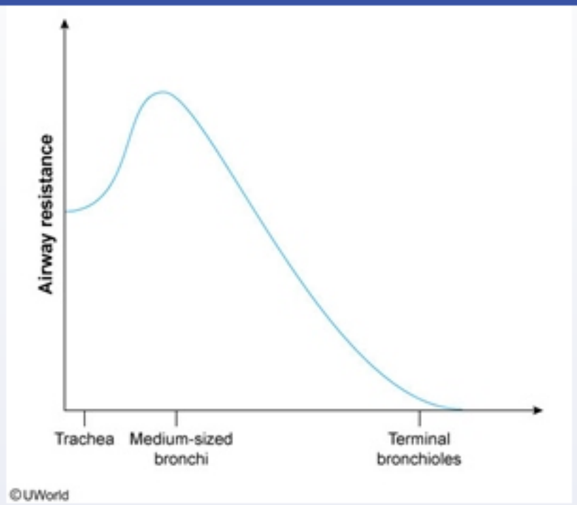

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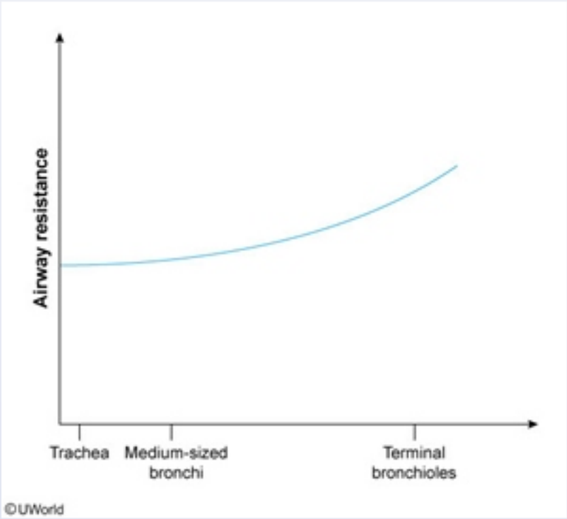

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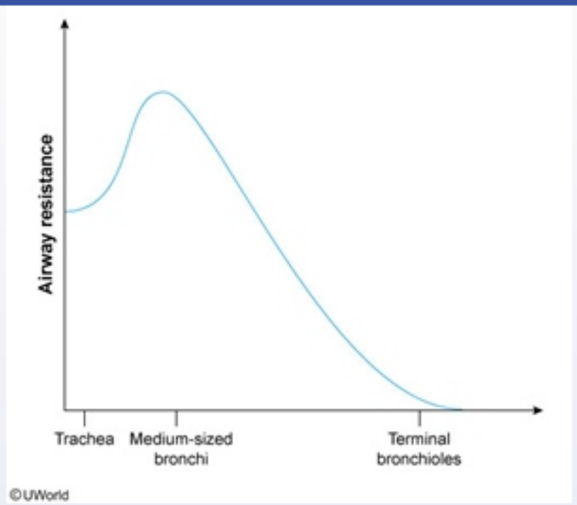
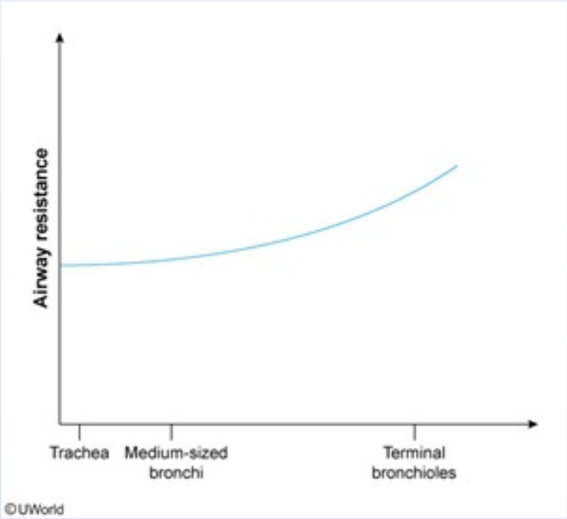
D. (49%)



E. (10%)



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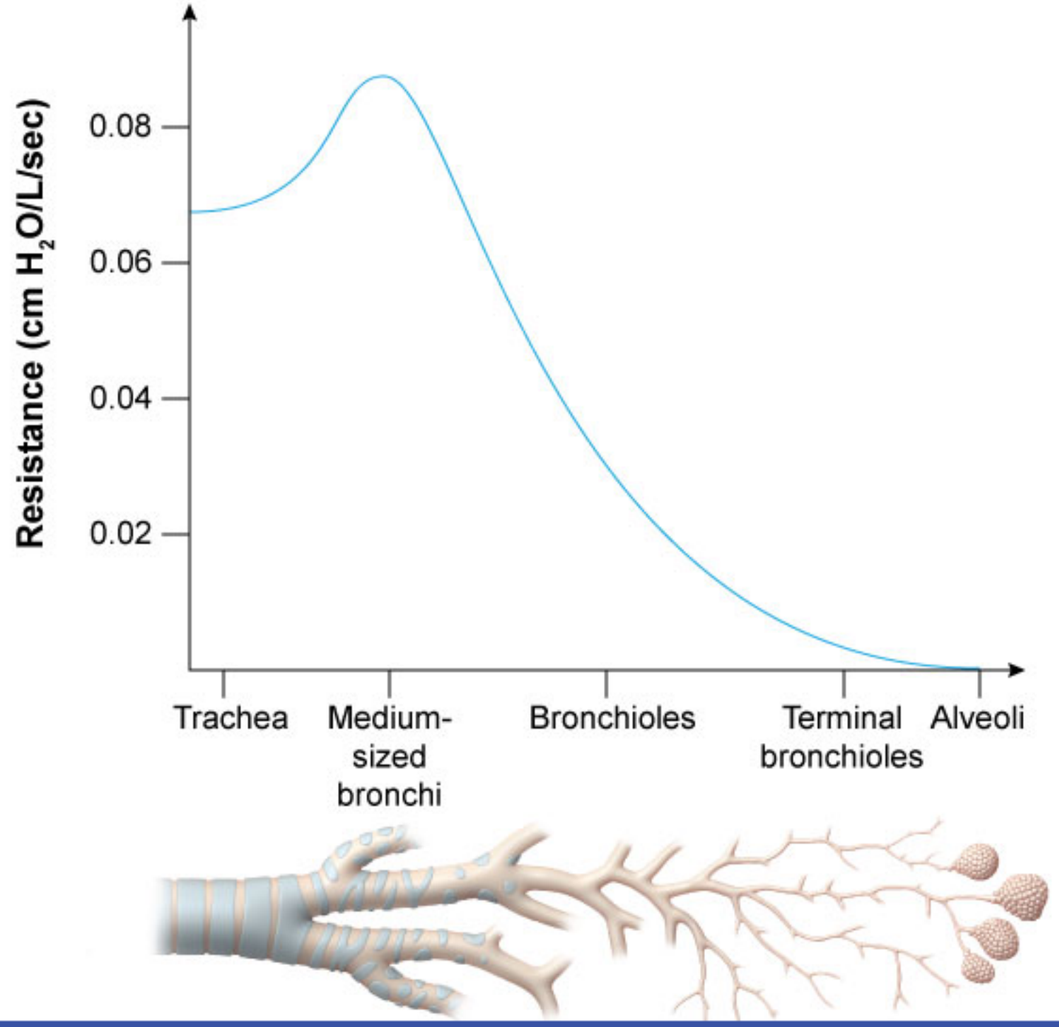
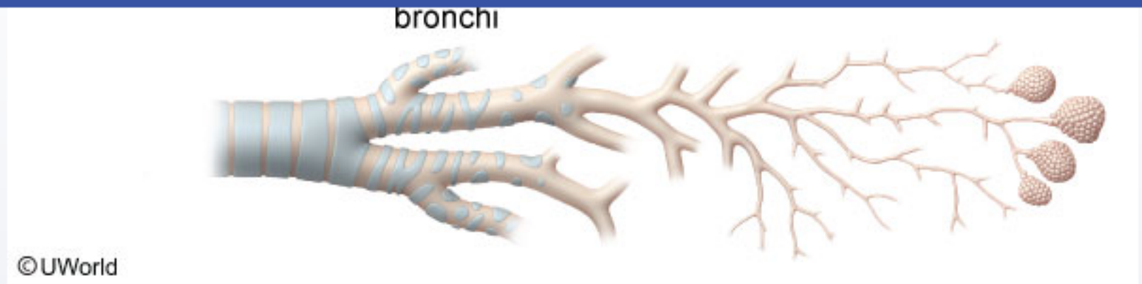
Airway resistance of the lower respiratory tract





The upper respiratory tract (eg, nasal passages, mouth, pharynx, larynx) accounts for about half of total airway resistance. The remainder comes from the **lower respiratory tract**, which begins at the trachea and proceeds through roughly 23 generations of airway bifurcation before reaching the alveoli (ie, the trachea divides into approximately 8×10^6 [2^{23}] smaller airways before reaching the alveoli). Because the **airways** at each level of the lower respiratory tract are **arranged in parallel**, airway resistance is determined by the total cross-sectional area of all the airways at that level; the **greater the total cross-sectional area**, the **lower the airway resistance**.

The cross-sectional area of the trachea is relatively small (~3.5 cm^2), but the total area of the **first few generations of bronchi** is even smaller, leading to an **initial small increase in resistance** from the trachea to the bronchi. However, from the medium-sized bronchi on, the total cross-sectional area at each level of the lower respiratory tract increases in step-wise fashion, creating a **progressive decline in airway resistance**. By the time the alveoli are reached, the total cross-sectional area is massive (~5×10^5 cm^2) and airway resistance is essentially zero.

Educational objective:
The airway resistance at each level of the lower respiratory tract is inversely related to the total cross-sectional area of all the airways at that level. Airway resistance is high in the trachea and reaches a peak in the medium-sized bronchi, where total cross-sectional area is at a minimum. Airway resistance then progressively decreases as total cross-sectional area increases through the smaller bronchioles, terminal bronchioles, and alveoli.

Physiology	Pulmonary & Critical Care	Respiratory physiology
Subject	System	Topic

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Researchers are studying pulmonary gas exchange in various physiological and pathological states using animal models. In one experiment, the partial pressure of oxygen (PO_2) in the upper airways is determined to be 150 mm Hg while breathing ambient air at rest. Analysis of the respiratory gases in a particular lung segment reveals the following:

Alveolar PO_2	104 mm Hg
Pulmonary venous PO_2	70 mm Hg
Pulmonary venous PCO_2	40 mm Hg

Which of the following best explains these respiratory gas findings?

A. Bronchopulmonary shunting
B. Diffusion impairment
C. Normal alveolar ventilation and perfusion
D. Physiologic intrapulmonary shunting
E. Poor alveolar ventilation

Submit

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Pulmonary venous PO_2	70 mm Hg
Pulmonary venous PCO_2	40 mm Hg

Which of the following best explains these respiratory gas findings?

A. Bronchopulmonary shunting (10%)

✓ B. Diffusion impairment (43%)

C. Normal alveolar ventilation and perfusion (26%)

D. Physiologic intrapulmonary shunting (11%)

E. Poor alveolar ventilation (7%)

Omitted
Correct answer
B

43%
Answered correctly

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Last Updated

Explanation

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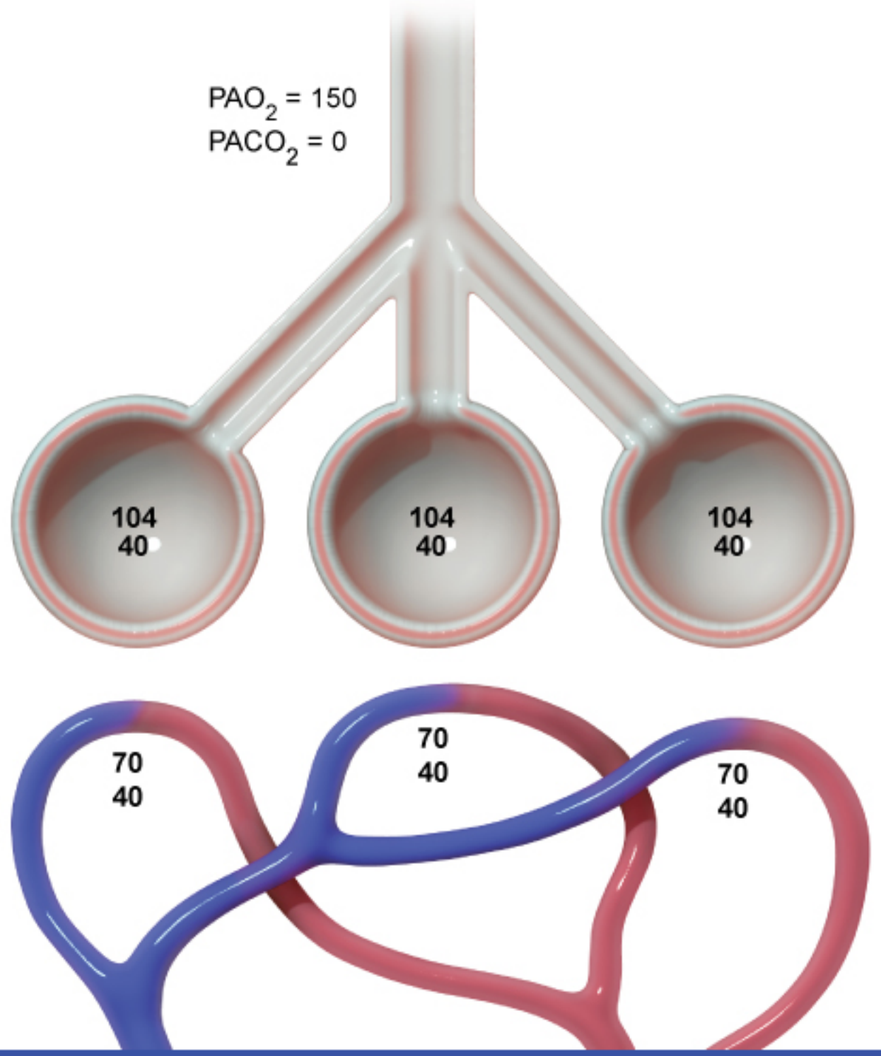
Diffusion impairment



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To pulmonary vein

Under normal conditions, the PO_2 of inspired ambient air is approximately 160 mm Hg. This value decreases to approximately 150 mm Hg in the trachea due to the partial pressure of water vapor. Normal **alveolar PO_2 is 104 mm Hg**, which lies between the tracheal (150 mm Hg) and systemic venous blood (40 mm Hg) PO_2 concentrations. Likewise, normal **alveolar PCO_2 is 40 mm Hg**, also between its respective tracheal (0 mm Hg) and systemic venous blood concentrations (45 mm Hg).

Transfer of O_2 and CO_2 between the blood and the alveoli depends on both perfusion and diffusion. Under normal resting conditions, diffusion of O_2 and CO_2 is a quick process, with blood needing to traverse only one-third of the total pulmonary capillary length to completely equilibrate. In this setting, gas exchange is perfusion-limited (ie, diffusion is fast enough that the total gas exchange depends only on the amount of blood supplied to the alveoli).

Diffusion-limited gas exchange takes place when diffusion across the alveolar membrane is relatively slow enough to become the major limitation to gas exchange. This can occur with exercise (due to extremely high perfusion volumes that the diffusion rate cannot keep up with) or with pathologic conditions that disrupt the alveolar membrane (eg, pulmonary fibrosis, emphysema) and slow diffusion. **CO_2 diffuses 20 times faster than O_2**, even when the alveolar membrane is somewhat disrupted; therefore, alveolar and capillary CO_2 concentrations typically fully equilibrate while alveolar and capillary O_2 concentrations do not.

In this experiment, there is a **large PO_2 gradient** between the alveoli (104 mm Hg) and the pulmonary venous blood (70 mm Hg) but pulmonary venous **PCO_2 is normal** (40 mm Hg), indicating incomplete gas exchange most likely due to diffusion impairment.

(Choice A) Bronchopulmonary shunting describes the normal small drop in PO_2 and small increase in PCO_2 that occurs due to the pulmonary veins receiving deoxygenated blood from the bronchial circulation. However, this normally only results in about a 4 mm Hg drop in PO_2 within the pulmonary veins.

(Choice C) In normal alveolar ventilation and perfusion, the alveolar and pulmonary capillary PO_2 rapidly reach equilibrium at 104 mm Hg.

(Choice D) Physiologic intrapulmonary shunting occurs when the alveoli fill with fluid (eg, pneumonia, pulmonary edema) or collapse (eg, atelectasis) and alveolar ventilation is essentially zero. This patient's alveolar PO_2 of 104 mm Hg is not consistent with shunting (alveolar PO_2 equilibrates with venous blood at 40 mm Hg when ventilation is zero).

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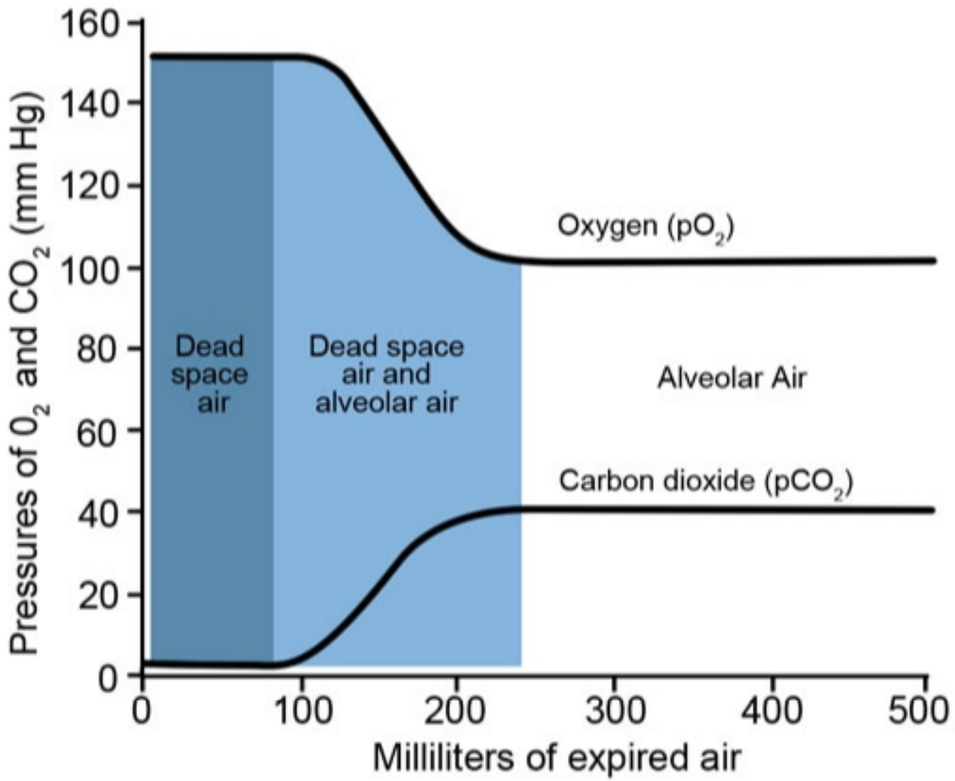

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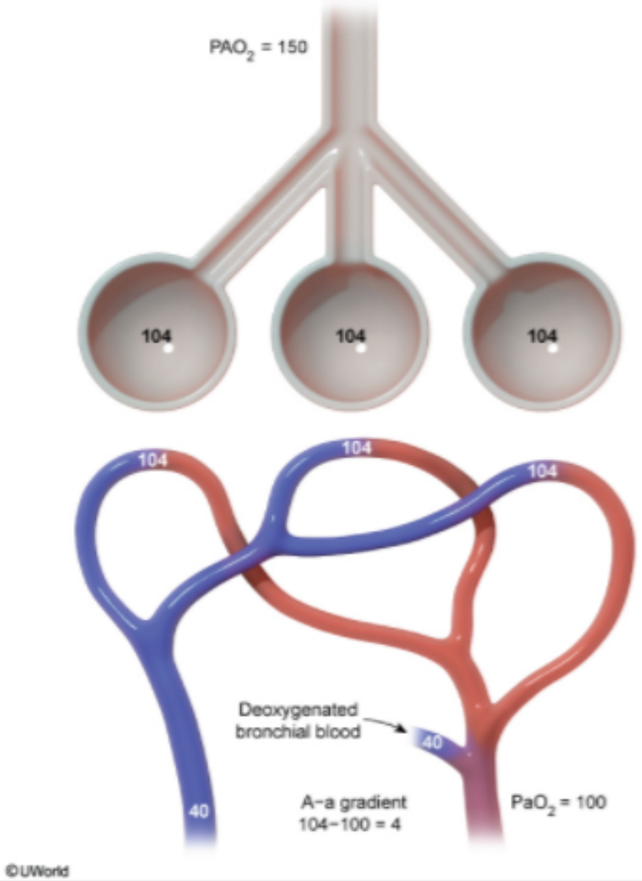
equilibrates with venous blood at 40 mm Hg when ventilation is zero).

this setting, gas exchange is perfusion-limited (ie, diffusion is fast enough that the total gas exchange depends only on the amount of blood

Exhibit Display

Normal bronchopulmonary shunting



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References

this setting, gas exchange is perfusion-limited (ie, diffusion is fast enough that the total gas exchange depends only on the amount of blood

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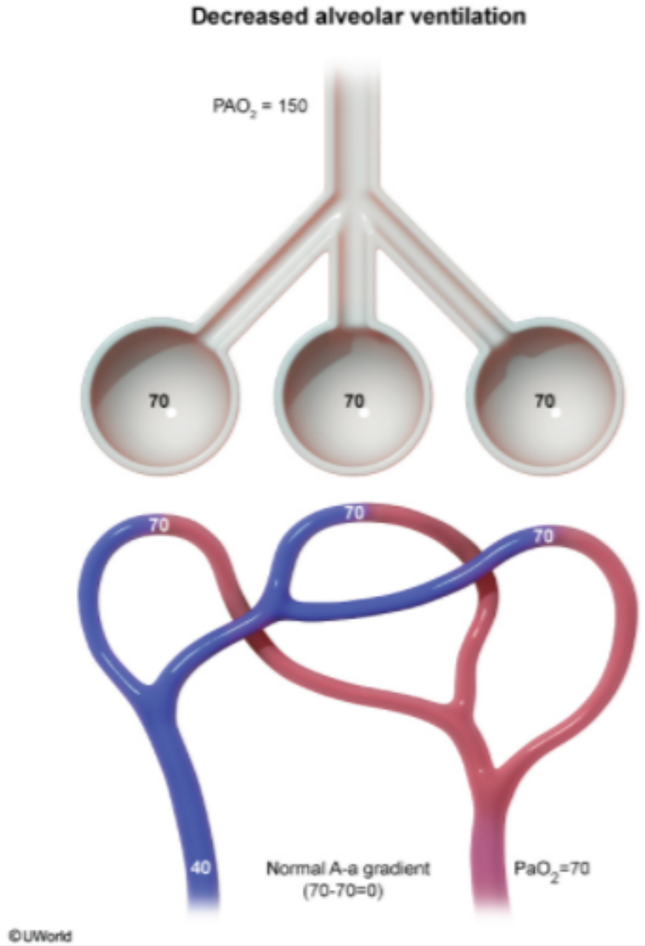

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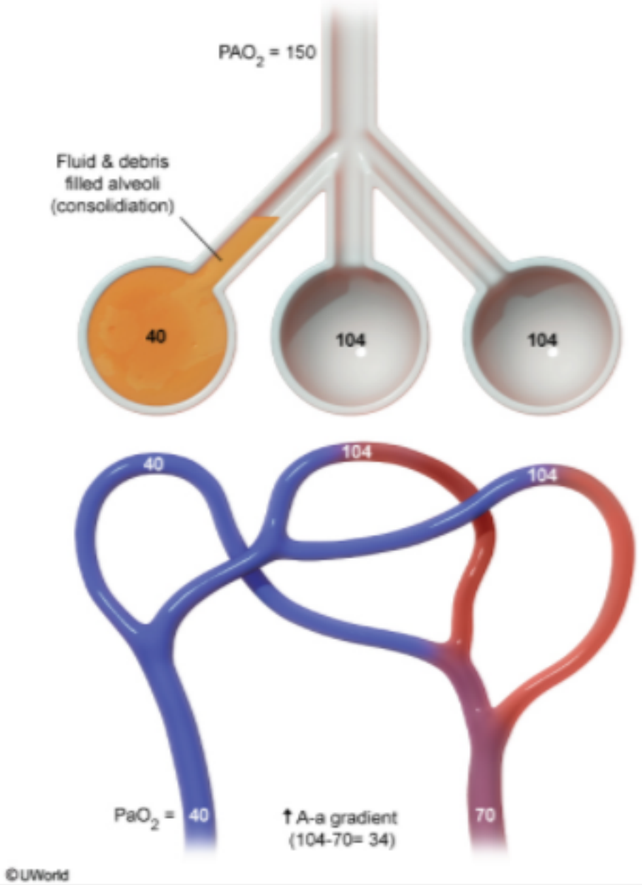
Exhibit Display

Physiologic intrapulmonary shunting with V/Q mismatch



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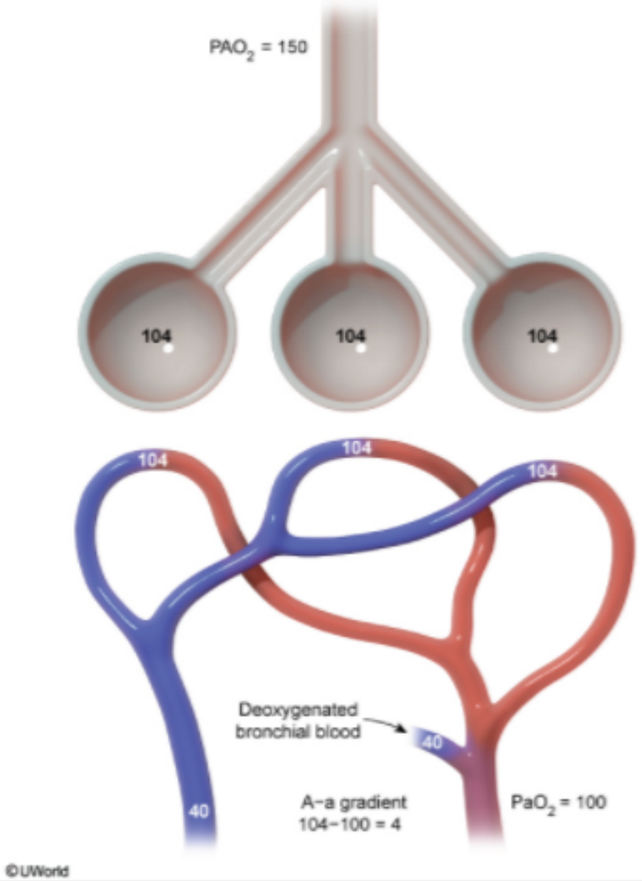
Normal bronchopulmonary shunting



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References

The following vignette applies to the next **2** items. The items in the set must be answered in sequential order. Once you click **Proceed to Next Item**, you will not be able to add or change an answer.

A 47-year-old man comes to the emergency department due to a 30-minute history of sudden-onset severe chest pain and shortness of breath. He is on an RV road trip with his family and has had pain in and swelling of the left leg for the past 2 days. The patient has no significant medical history and takes no medications. Temperature is 37.2 C (99 F), blood pressure is 90/56 mm Hg, pulse is 124/min, and respirations are 32/min. Oxygen saturation is 82% on room air. BMI is 36 kg/m^2. ECG shows sinus tachycardia. Chest x-ray shows no abnormalities.

Item 1 of 2

Which of the following is most likely increased in this patient?

- A. Functional residual capacity
- B. Lung diffusion capacity
- C. Physiologic dead space
- D. Pulmonary compliance
- E. Total airway resistance

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Item 1 of 2

Which of the following is most likely increased in this patient?

- A. Functional residual capacity (2%)
- B. Lung diffusion capacity (3%)
- ✓ C. Physiologic dead space (83%)
- D. Pulmonary compliance (1%)
- E. Total airway resistance (9%)

Omitted
Correct answer
C

83%
Answered correctly

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Explanation

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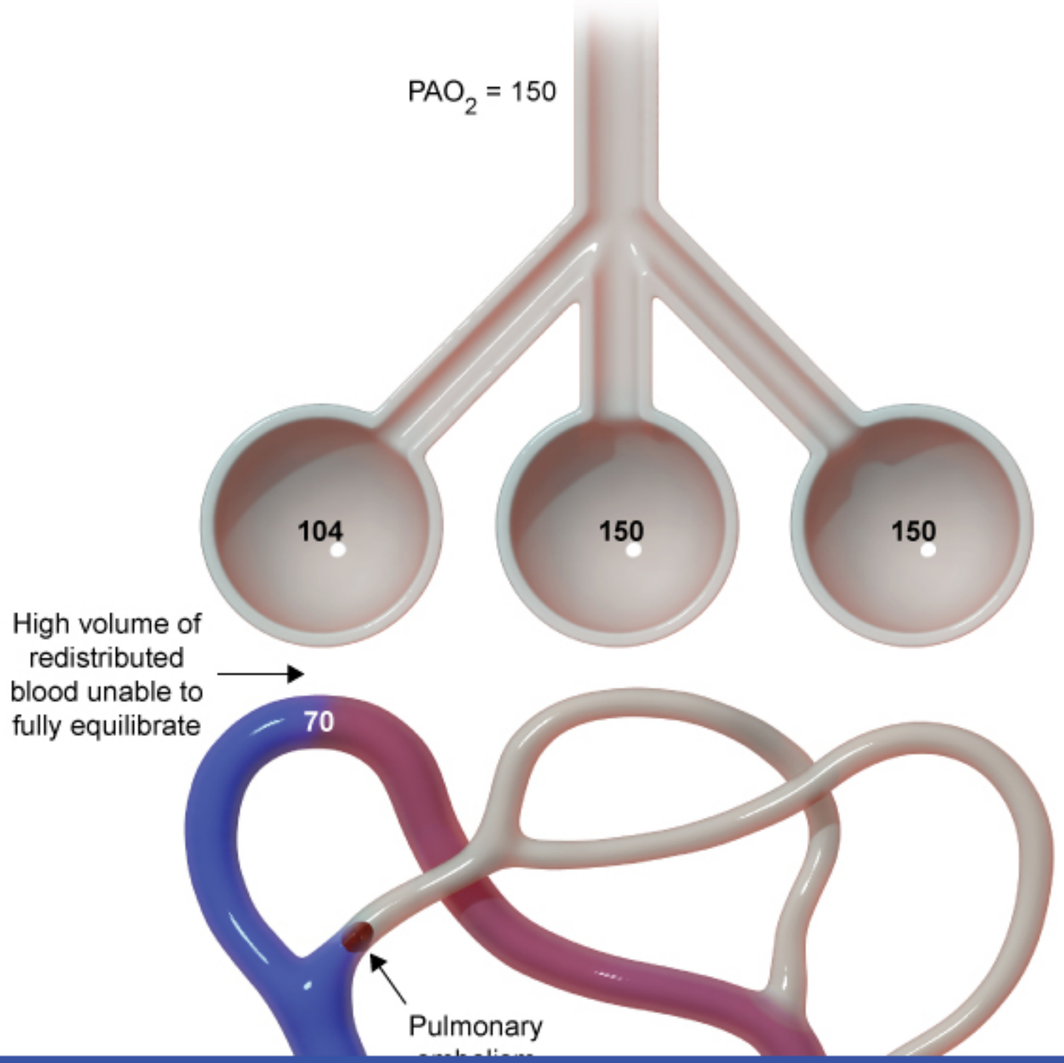
Pulmonary embolism



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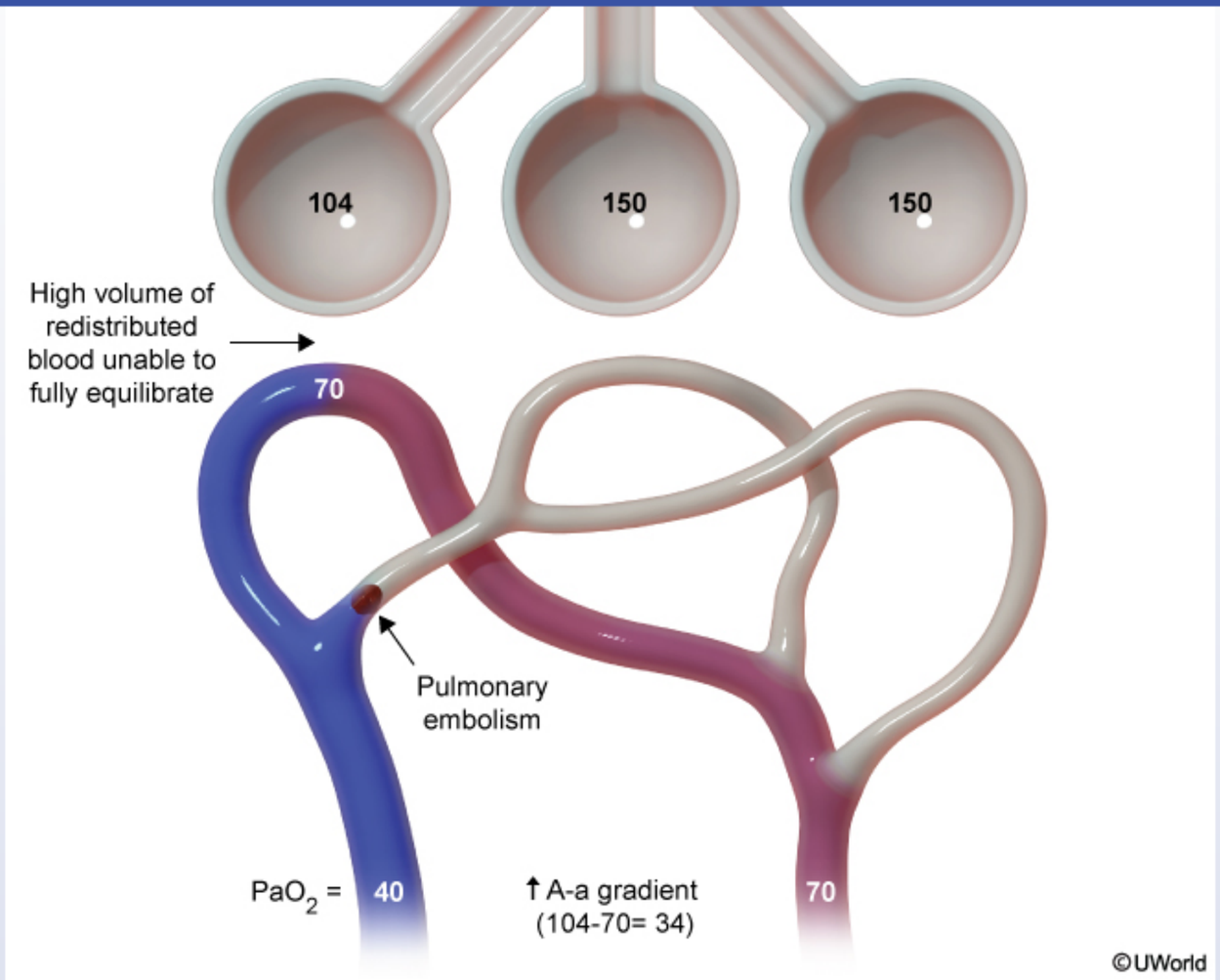

This patient has developed a deep venous thrombosis in his left leg following a lengthy car trip and now has clinical features highly consistent with acute **pulmonary embolism** (PE). Obstruction of the pulmonary circulation by an embolus causes **increased dead space ventilation** (ie, alveoli are ventilated but not perfused); the term "dead space" refers to the volume of inspired air that does not participate in gas exchange. As dead space ventilation increases, blood that continues to flow through the pulmonary circulation cannot be fully oxygenated by the decreased number of

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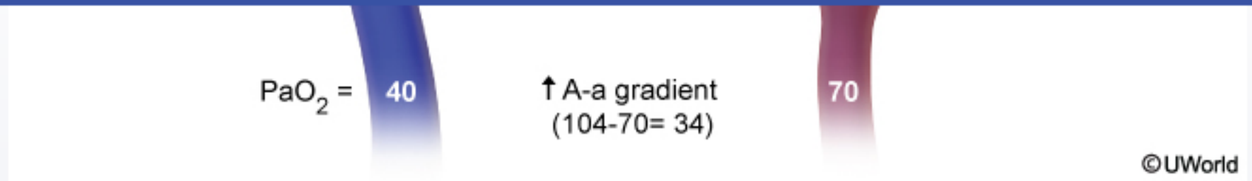

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(Choice A) Functional residual capacity refers to the volume of air remaining in the lungs after a normal expiration. It is increased in chronic obstructive pulmonary disease (COPD) due to air trapping; however, it is unchanged in PE.

(Choice B) Diffusion capacity is reduced by conditions that disrupt the alveolar-capillary interface (eg, pulmonary fibrosis), but it is not altered in PE.

(Choice D) Pulmonary compliance (ability to expand) is reduced in restrictive lung disease (eg, pulmonary fibrosis) and is increased in COPD (due to emphysematous destruction of the distal airways). However, it is not significantly altered in the setting of PE.

(Choice E) Total airway resistance is increased by bronchoconstriction, which occurs in patients with asthma. PE does not affect airway resistance.

Educational objective:
Pulmonary embolism causes dead space ventilation, which leads to hypoxemia due to the consequent ventilation/perfusion mismatch.

Physiology	Pulmonary & Critical Care	Pulmonary embolism
Subject	System	Topic

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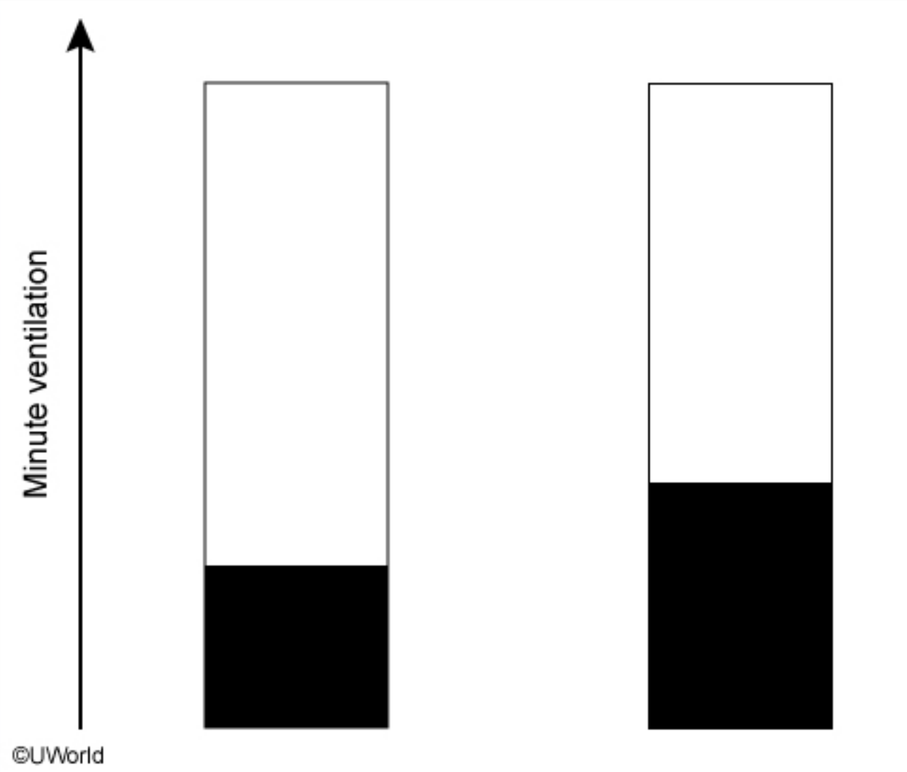
Item 2 of 2

During evaluation, the patient becomes unresponsive and develops cardiac arrest with pulseless electrical activity. Cardiopulmonary resuscitation and intubation are performed, and the patient is placed on a mechanical ventilator. Once stabilized, he is admitted to the intensive care unit, and appropriate treatment is administered. Several days later, a spontaneous-breathing trial is performed to determine readiness to wean off the ventilator. After the mechanical ventilator settings are adjusted, the following changes are noted as reflected on the graph below. Dead space ventilation is shaded in black.



Which of the following breathing patterns most likely contributed to this patient's change from the left bar to the right on the graph above?

Which of the following breathing patterns most likely contributed to this patient's change from the left bar to the right on the graph above?

	Respiratory Rate	Tidal Volume
A.	↑	↑
B.	↑	↓
C.	↓	↑
D.	↓	↓

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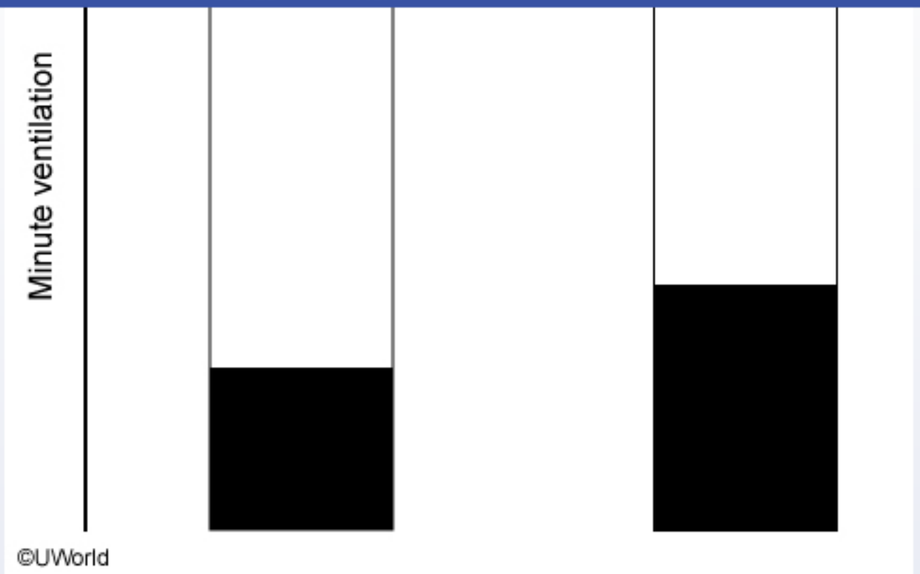

Which of the following breathing patterns most likely contributed to this patient's change from the left bar to the right on the graph above?

	Respiratory Rate	Tidal Volume
A. (13%)	↑	↑
✓ B. (60%)	↑	↓
C. (15%)	↓	↑
D. (10%)	↓	↓

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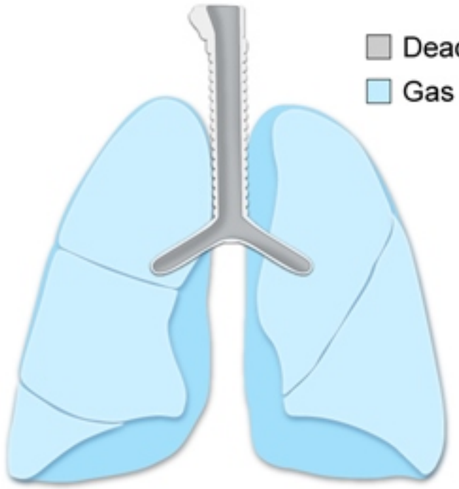
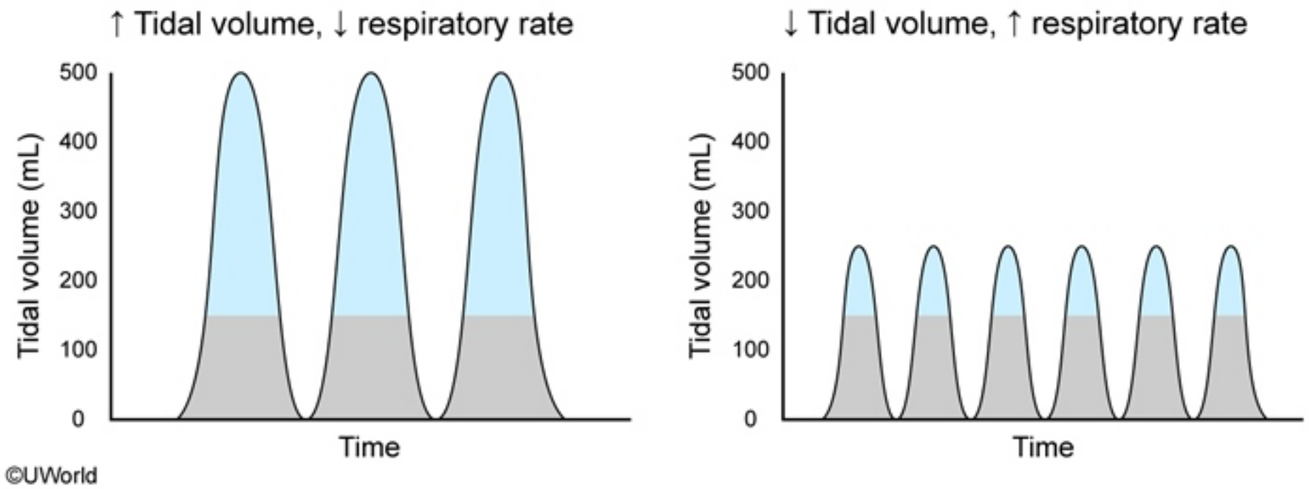
Low tidal volume increases dead-space ventilation





Physiologic (total) dead space includes the anatomic dead space (the permanent volume of dead space within the conducting airways) plus the

Time Time

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Physiologic (total) dead space includes the anatomic dead space (the permanent volume of dead space within the conducting airways) plus the alveolar dead space (the volume of air in the respiratory zone that does not participate in gas exchange). Increases in physiologic dead space occur in many lung diseases, including pulmonary embolism, emphysema, and acute respiratory distress syndrome.

Dead space volume remains relatively constant on a minute-by-minute basis. However, **lower tidal volumes** increase the proportion of each breath composed of dead space. If **minute ventilation** (tidal volume x respiratory rate) is **unchanged**, the consequence of the low-tidal-volumes is an **increase in dead space ventilation** (inefficient breathing).

Patients undergoing **mechanical ventilation weaning** typically have weakened respiratory muscles and therefore tend to breathe at low tidal volumes to minimize the work of breathing. This hypoventilation triggers an increase in respiratory drive that **increases respiratory rate** to maintain minute ventilation. When patients are being weaned off the ventilator, the ratio of their respiratory rate/tidal volume, known as the rapid shallow breathing index (RSBI), is measured; a low RSBI indicates relatively high tidal volumes, relatively efficient breathing, and a lower likelihood of recurrent respiratory failure once ventilatory support is discontinued.

(Choice A) Increases in both respiratory rate and tidal volume result in increased minute ventilation. However, the graph shows that minute ventilation remains the same after ventilator adjustment.

(Choice C) A decrease in respiratory rate and an increase in tidal volume would keep minute ventilation constant; however, the total volume of dead-space air breathed each minute would decrease rather than increase.

(Choice D) Decreases in both respiratory rate and tidal volume would result in decreased, rather than constant, minute ventilation.

Educational objective:
Patients being weaned from mechanical ventilation typically breathe at low tidal volumes, with a compensatory increase in respiratory rate to maintain minute ventilation. Because at low tidal volumes a higher proportion of each breath is composed of dead space, this type of breathing leads to an increase in wasted ventilation (inefficient breathing).

Physiology	Pulmonary & Critical Care	Pulmonary embolism
Subject	System	Topic

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A 32-year-old woman comes to the office with worsening shortness of breath. She has the following arterial blood results:

PaO_2	normal
% saturation (SaO_2)	normal
Oxygen content	low

Which of the following is the most likely cause of these results?

A. Chronic blood loss
B. Cyanide intoxication
C. High altitude
D. Morbid obesity
E. Unrepaired Fallot tetralogy

Submit

A 32-year-old woman comes to the office with worsening shortness of breath. She has the following arterial blood results:

PaO_2	normal
% saturation (SaO_2)	normal
Oxygen content	low

Which of the following is the most likely cause of these results?

- A. Chronic blood loss (68%)
- B. Cyanide intoxication (16%)
- C. High altitude (10%)
- D. Morbid obesity (3%)
- E. Unrepaired Fallot tetralogy (1%)

Omitted
Correct answer
A

68%
Answered correctly

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Explanation

	PaO_2	SaO_2	Oxygen content

Explanation

	PaO_2	SaO_2	Oxygen content
CO poisoning	Normal	Decreased*	↓
Cyanide poisoning	Normal	Normal	Normal
Anemia (↓ Hgb)	Normal	Normal	↓
Polycythemia (↑ Hgb)	Normal	Normal	↑
High altitude	↓	↓	↓

*Detected as normal using standard probes.

CO = carbon monoxide; **Hgb** = hemoglobin; **PaO_2** = arterial oxygen tension; **SaO_2** = arterial oxygen saturation.

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Oxygen is carried in the blood both as a dissolved gas and in combination with hemoglobin. The total oxygen content of the blood is determined primarily by the amount of hemoglobin in the blood and its percentage of oxygen saturation (SaO_2). Dissolved oxygen is not bound to hemoglobin and accounts for a very small proportion of the total oxygen content of blood due to low solubility in plasma. Changes in arterial oxygen tension (PaO_2) affect both the SaO_2 and the amount of oxygen dissolved in the plasma; however, the change in SaO_2 is far more influential on the total oxygen content of the blood.

This patient has arterial pO_2 (PaO_2) and SaO_2 within the normal range, but decreased total blood oxygen content (CaO_2). If the **PaO_2 and SaO_2 are both normal**, the lower total blood oxygen content is most likely secondary to a **lower hemoglobin concentration**. A common cause of

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This patient has arterial pO_2 (PaO_2) and SaO_2 within the normal range, but decreased total blood oxygen content (CaO_2). If the **PaO_2 and SaO_2 are both normal**, the lower total blood oxygen content is most likely secondary to a **lower hemoglobin concentration**. A common cause of anemia in premenopausal women is **chronic blood loss** secondary to menstruation.

(Choice B) Cyanide inhibits cellular oxidative phosphorylation by inhibiting Fe^{3+} in cytochrome c oxidase, lowering peripheral tissue oxygen consumption. Arterial PaO_2, SaO_2, and CaO_2 remain unchanged, but venous oxygen content rises and the arterial-venous oxygen gradient falls. Cyanide may also bind to the ferrous (Fe^{2+}) iron of hemoglobin to form cyanohemoglobin, but only in small amounts that do not appreciably change arterial oxygen content.

(Choice C) Reduced alveolar oxygen tension (PAO_2) (eg, at high altitude) or disruption of gas exchange at the alveolar-capillary interface can reduce the PaO_2 and SaO_2. In addition, factors that reduce the affinity of hemoglobin for oxygen (eg, acidosis) can lower SaO_2 (Bohr-Haldane effect).

(Choice D) Obesity causes alveolar hypoventilation due to reduced chest wall compliance. Obese individuals also have increased lower lobe perfusion causing ventilation perfusion mismatch. These factors, in combination with other complex mechanisms, lead to hypoxemia (low PaO_2), low SaO_2, and hypercapnia.

(Choice E) In tetralogy of Fallot, mixing of deoxygenated and oxygenated blood occurs due to ventricular septal defect, lowering PaO_2 of the left ventricle. The aorta overrides the right and left ventricles, delivering blood with low arterial PaO_2 and SaO_2 to the periphery.

Educational objective:
The 3 variables that affect the total oxygen content of blood are hemoglobin concentration, oxygen saturation of hemoglobin (SaO_2), and the partial pressure of oxygen dissolved in blood (PaO_2). Anemia is characterized by decreased hemoglobin concentration in the setting of normal SaO_2 and PaO_2.

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Physiology	Pulmonary & Critical Care	Iron deficiency anemia
Subject	System	Topic

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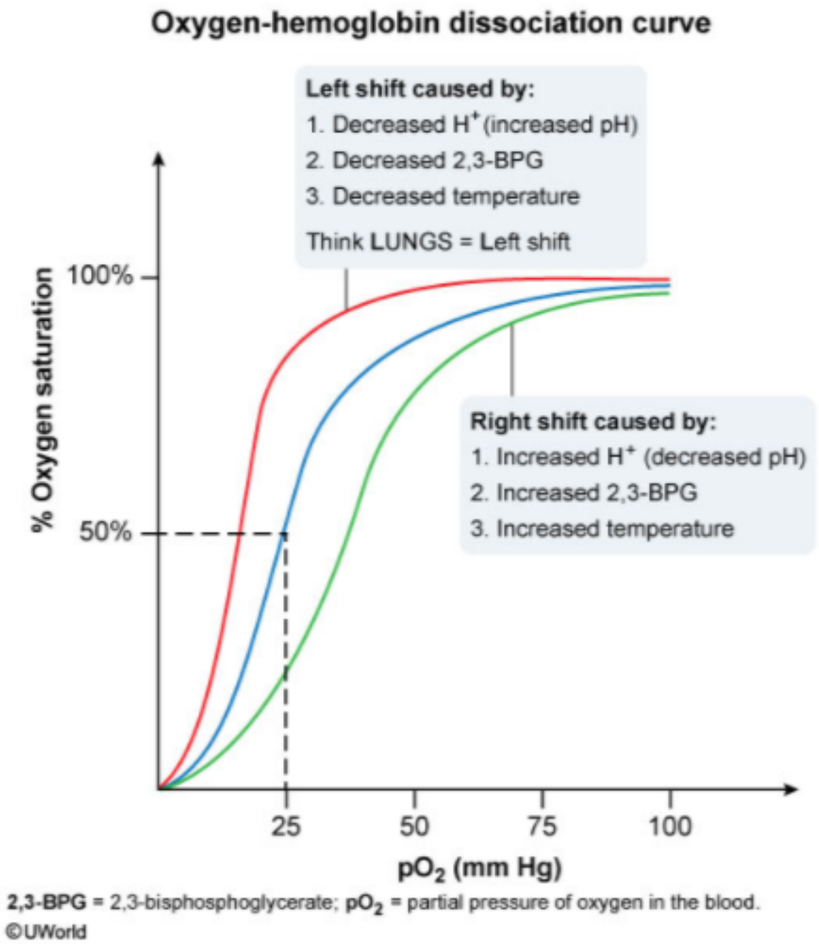

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Physiology	Pulmonary & Critical Care	Iron deficiency anemia
Subject	System	Topic

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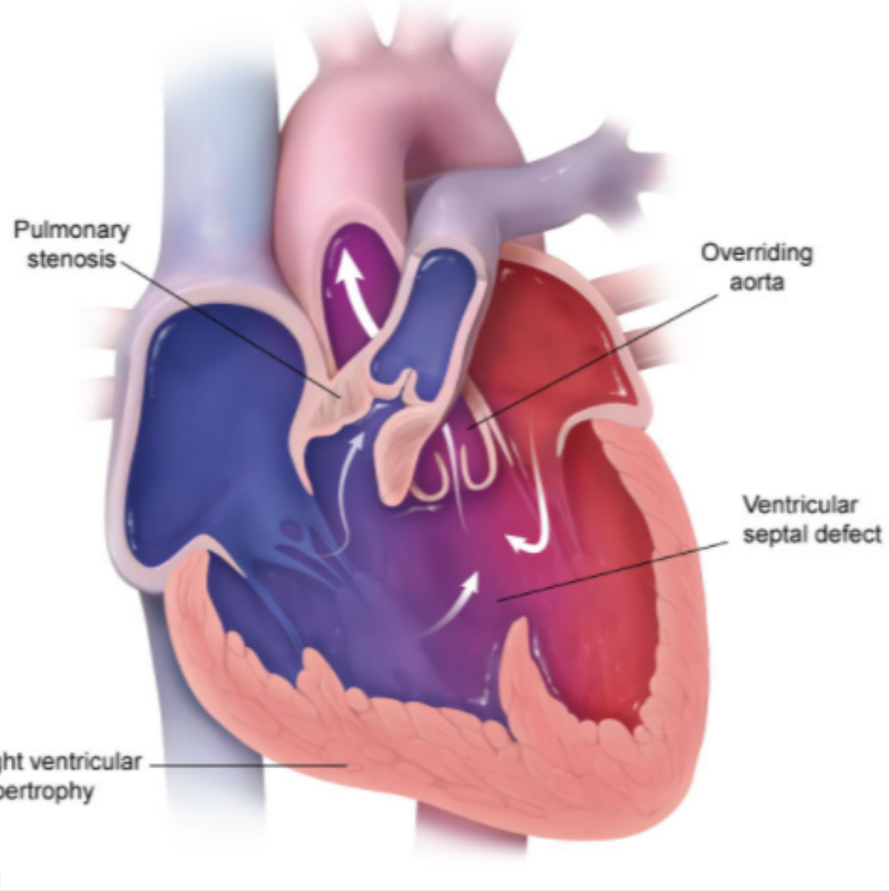
Tetralogy of Fallot



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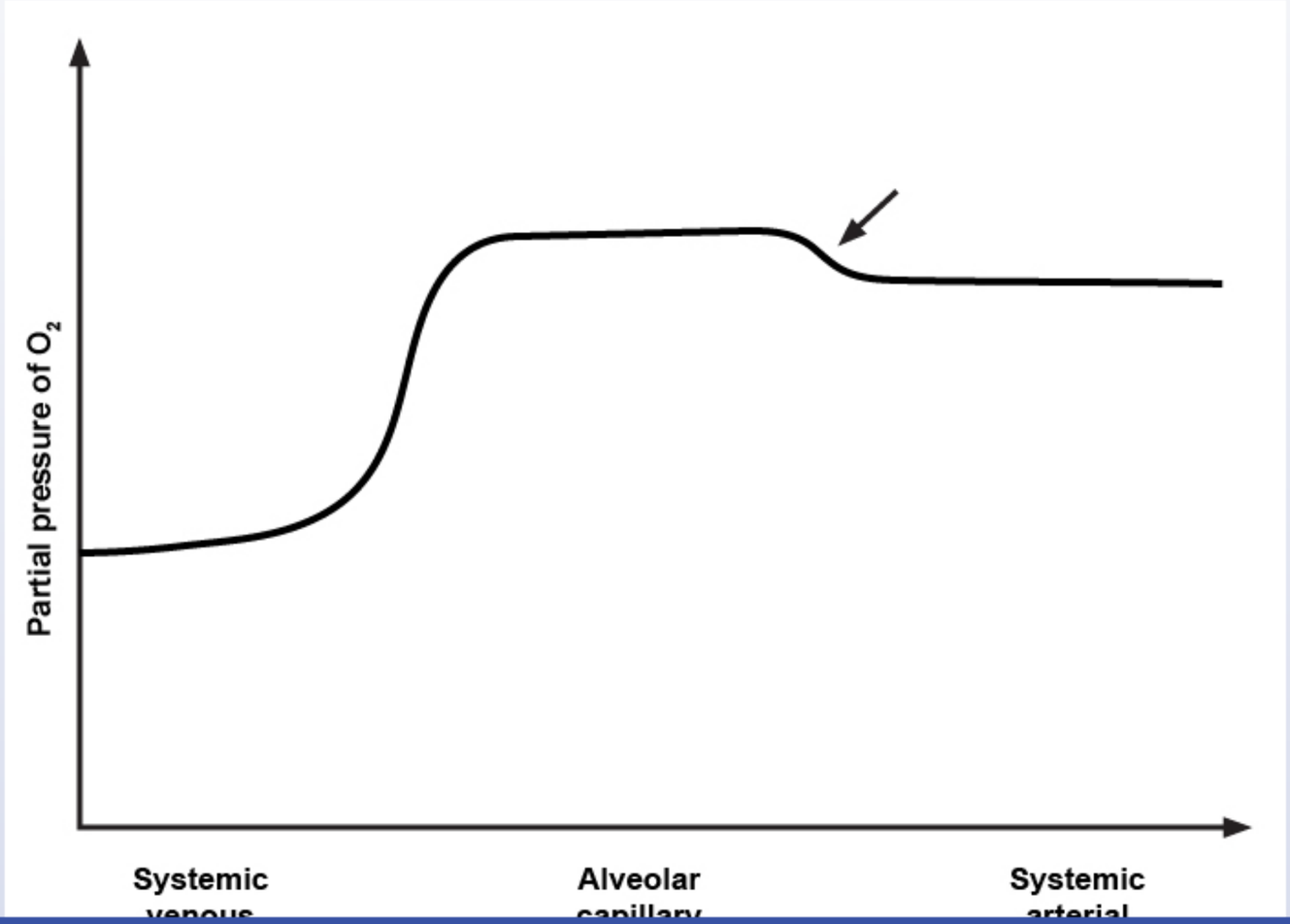
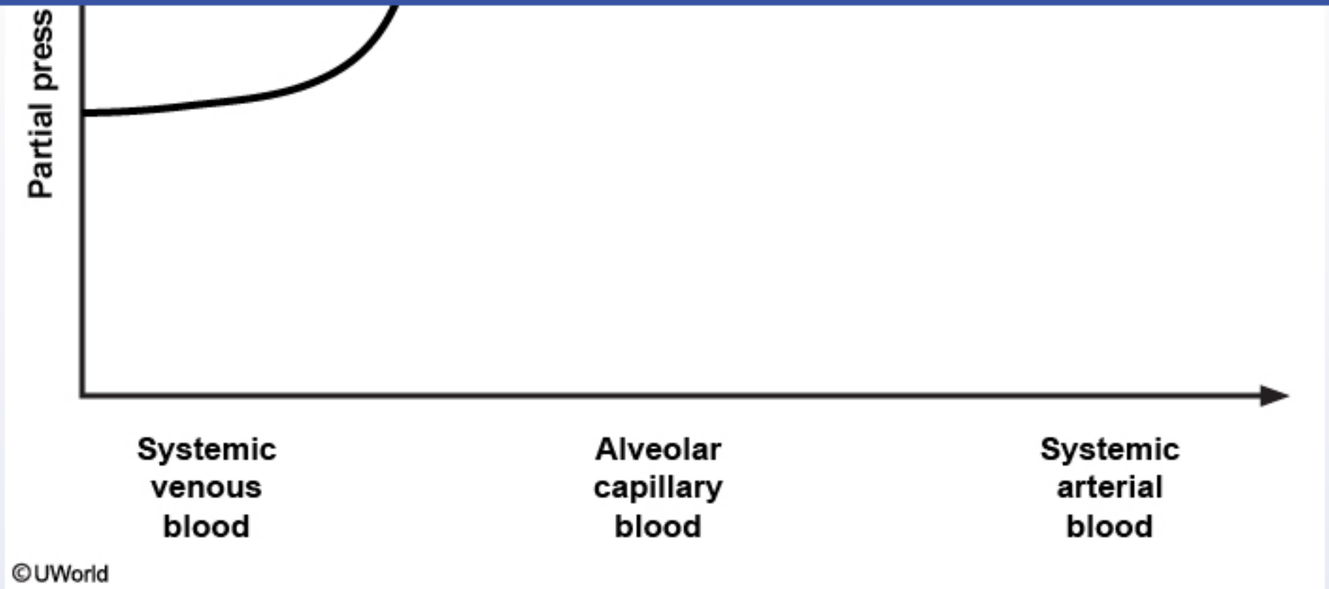
A 24-year-old healthy college student enrolls into a research study investigating the factors affecting blood oxygen content. The study is performed at sea level, on room air with no additional oxygen. A technique is devised to measure the accurate partial pressure of oxygen in the blood as it flows through the circulation. Blood samples are obtained from the vena cavae, alveolar capillaries, and the aorta. All data are plotted, and the curve obtained is shown in the graph below.





Which of the following factors most likely explains the change in partial pressure indicated by the arrow?

- A. Diffusion-limited oxygenation
- B. Increased dead space ventilation
- C. Mixture with deoxygenated blood
- D. Perfusion-limited oxygenation
- E. Shift in the hemoglobin dissociation curve

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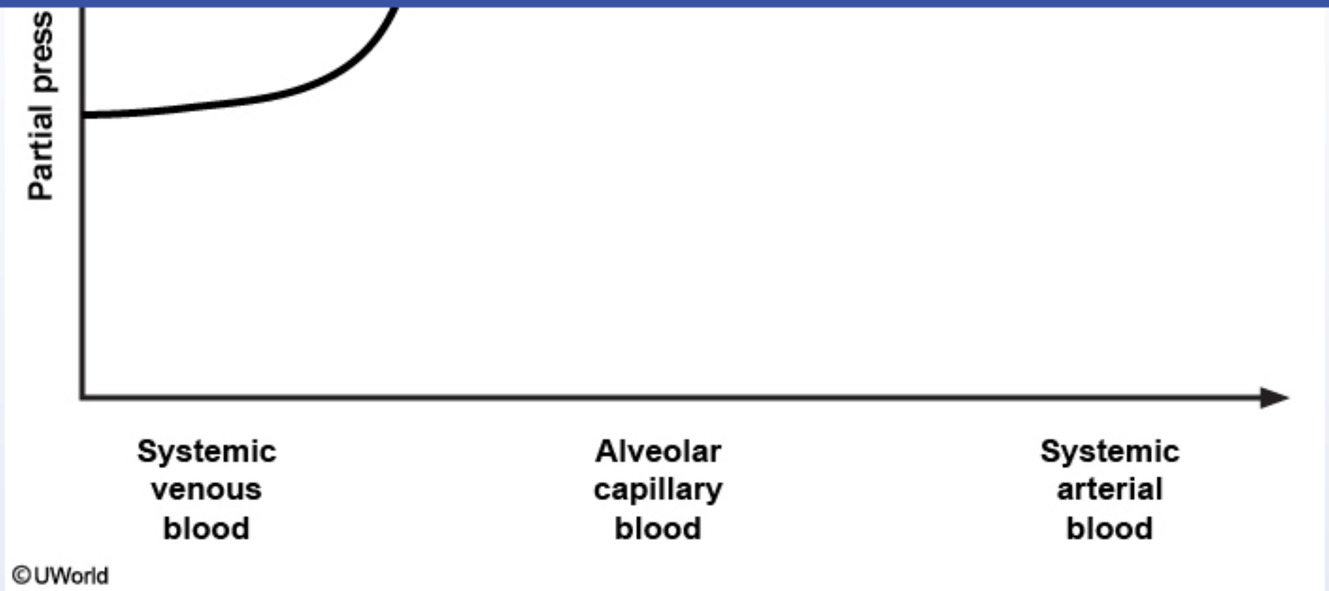

Which of the following factors most likely explains the change in partial pressure indicated by the arrow?

- A. Diffusion-limited oxygenation (10%)
- B. Increased dead space ventilation (2%)
- ✓ C. Mixture with deoxygenated blood (62%)
- D. Perfusion-limited oxygenation (14%)
- E. Shift in the hemoglobin dissociation curve (9%)

Omitted
Correct answer

62%
Answered correctly

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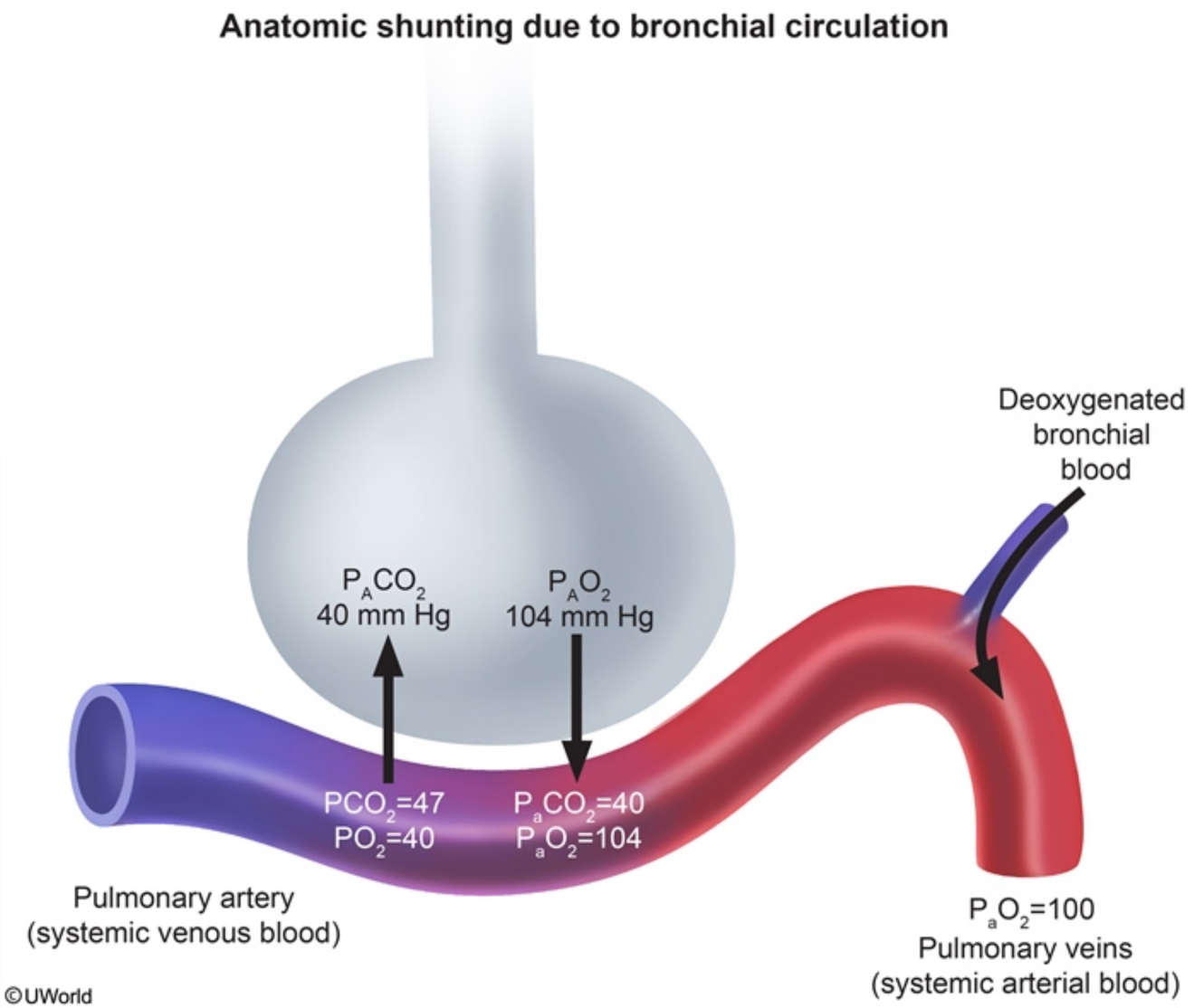


The graph illustrates the pO_2 of blood as it moves through the lungs and into the systemic circulation. Blood in the pulmonary arteries comes from

The graph illustrates the pO_2 of blood as it moves through the lungs and into the systemic circulation. Blood in the pulmonary arteries comes from the systemic venous system and is normally deoxygenated. As blood moves through the pulmonary capillaries, it becomes progressively more oxygenated until it equilibrates with the alveolar pO_2 (~104 mm Hg when breathing room air). This is represented by the curve's first upward deflection and subsequent plateau. However, blood in the left atrium and ventricle has a slightly lower pO_2 (~100 mm Hg) than blood in the pulmonary capillaries. This is due to the **mixing of deoxygenated blood** with oxygenated blood from the pulmonary veins and is represented by the downward deflection identified by the arrow. This deoxygenated blood comes from the following sources:

1. The **bronchial arteries** carry blood to the bronchi and bronchioles and, together with the pulmonary artery, form the dual blood supply to the lungs. The **bronchial veins** return only a portion of this blood to the right heart via the azygos and hemi-azygos veins; most of the blood supplied by the bronchial arteries returns to the left heart via the **pulmonary veins**.
2. Small cardiac (**thebesian**) veins that drain into the left atrium and ventricle also contribute to normal anatomic shunting.

(Choice A) Hypoxia due to a diffusion limitation frequently results from pulmonary fibrosis, acute respiratory distress syndrome, emphysema, or hyaline membrane disease of the infant. In diffusion-limited gas exchange, the blood pO_2 does not equilibrate with the alveolar pO_2 by the end of its traversal through the alveolar capillaries.

(Choice B) Dead space ventilation (wasted ventilation) refers to the volume of inspired air that does not participate in gas exchange. Anatomic dead space refers to the volume of air that remains in the conducting parts of the airways, such as the bronchi and bronchioles. Alveolar dead space refers to the volume of air in the alveoli that cannot participate in gas exchange due to poor perfusion.

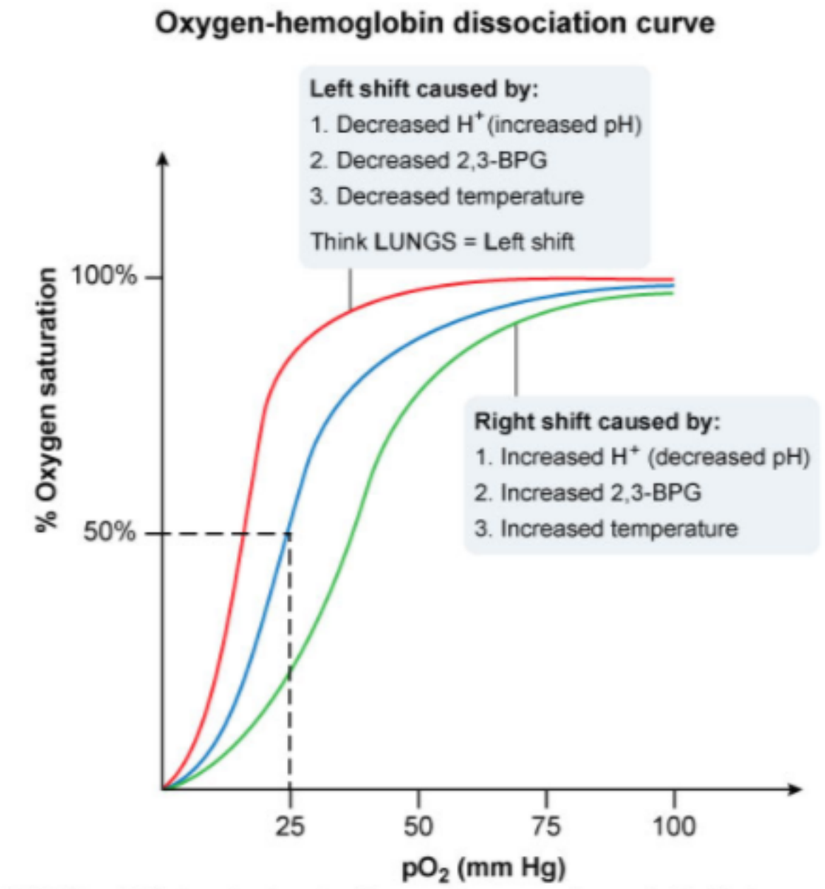
(Choice D) Perfusion-limited gas exchange occurs in the normal physiologic resting state, as equilibration of the blood with the alveolar gas is complete by the time the blood traverses one-third of the total pulmonary capillary length.

(Choice E) The hemoglobin dissociation curve shifts to the right in the systemic capillaries to increase oxygen delivery to the body tissues. Increases in pCO_2, temperature, and 2,3-diphosphoglycerate concentration cause right-shifting of the curve; the opposite conditions cause a left shift and favor oxygen loading in the lungs.

Educational objective:
The pO_2 in the left atrium and ventricle is lower than that in the pulmonary capillaries due to mixing of oxygenated blood from the pulmonary veins with deoxygenated blood from the bronchial circulation and thebesian veins.

The graph illustrates the pO_2 of blood as it moves through the lungs and into the systemic circulation. Blood in the pulmonary arteries comes from

Exhibit Display



2,3-BPG = 2,3-bisphosphoglycerate; pO_2 = partial pressure of oxygen in the blood.

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with deoxygenated blood from the bronchial circulation and thebesian veins

the downward deflection identified by the arrow. This deoxygenated blood comes from the following sources:

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Educational objective:
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Physiology	Pulmonary & Critical Care	Respiratory physiology
Subject	System	Topic

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A 45-year-old man is evaluated for persistent cough and progressive dyspnea on exertion. The patient has no medical issues but has been exposed to large quantities of coal dust while working as a miner for the past 15 years. Chest imaging reveals small, nodular opacities in the upper lobes. Lung biopsy shows fine carbon particles within the patient's respiratory bronchioles and alveolar ducts. Which of the following mechanisms is most directly responsible for clearing the foreign particles from this patient's respiratory tract?

A. Coughing and sneezing

B. Immunologic memory

C. Mucociliary transport

D. Phagocytosis

E. Upper airway trapping

Submit

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- A. Coughing and sneezing (3%)
- B. Immunologic memory (0%)
- C. Mucociliary transport (36%)
- ✓ D. Phagocytosis (58%)
- E. Upper airway trapping (1%)

Omitted
Correct answer
D

58%
Answered correctly

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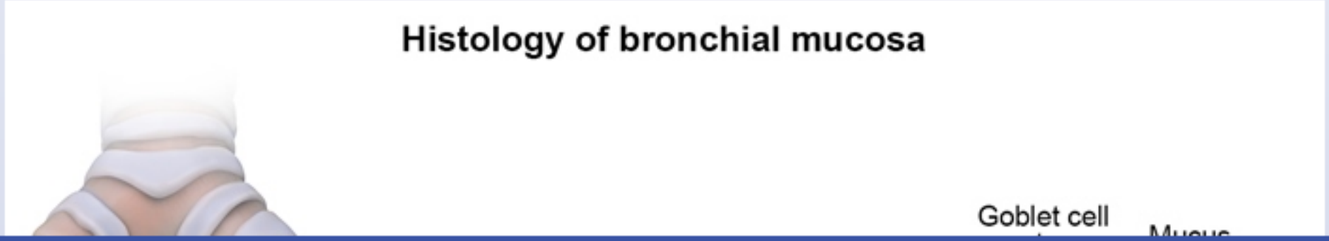
Time Spent

05/03/2020
Last Updated

Explanation



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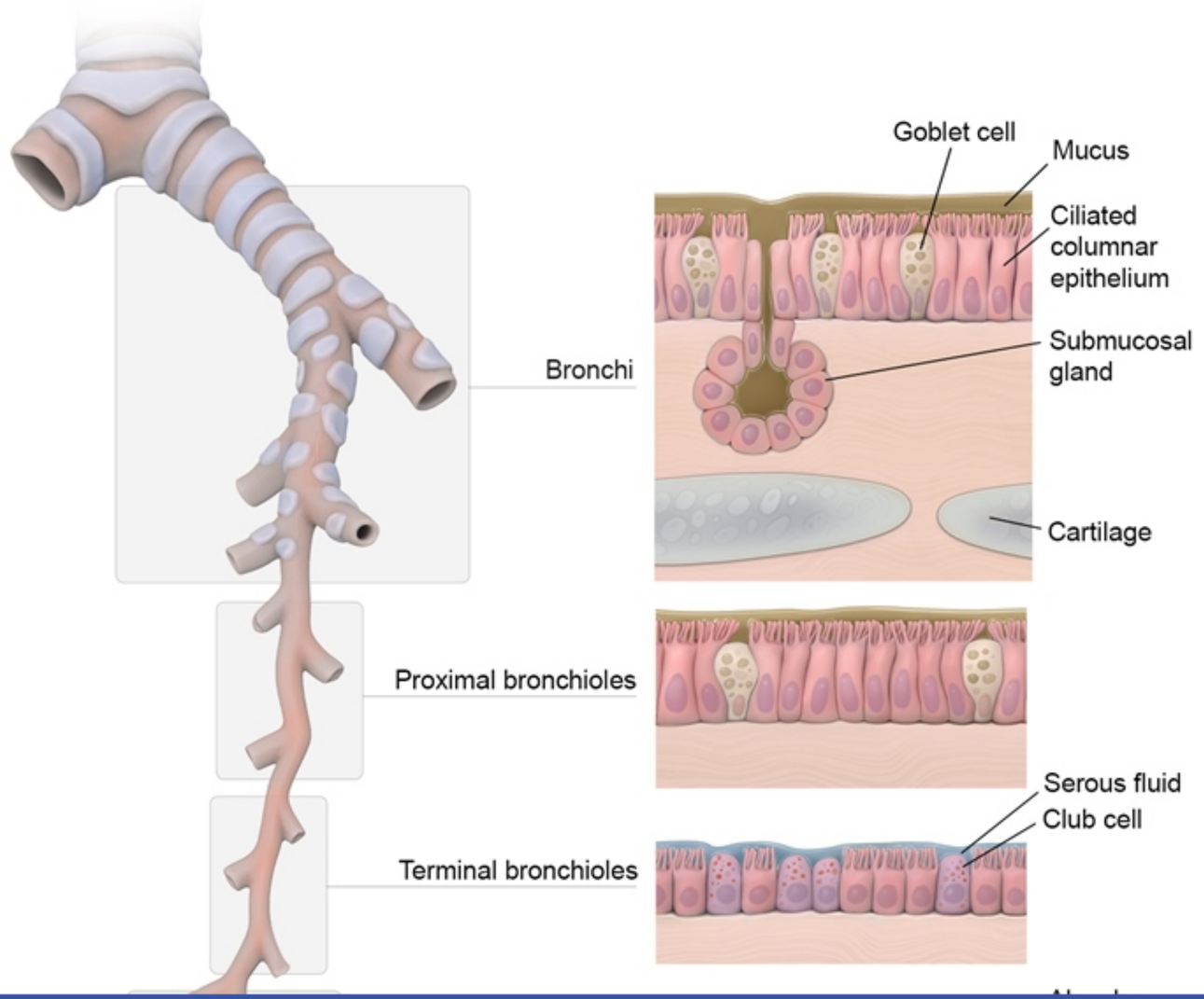
Histology of bronchial mucosa



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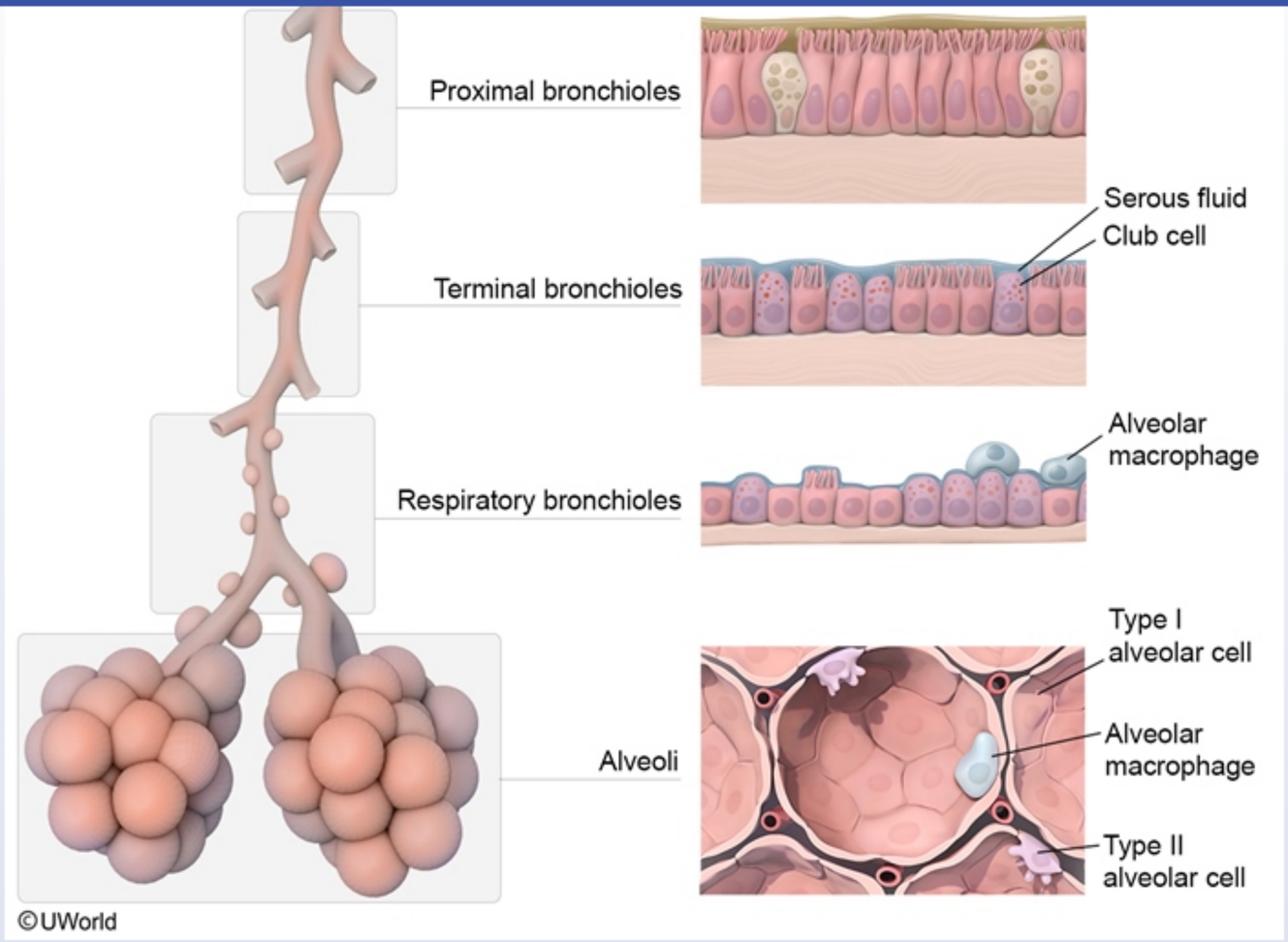

This patient has **coal worker pneumoconiosis**, a form of interstitial lung fibrosis secondary to long-term inhalation of coal particles.

Inorganic dust is constantly being inhaled and must be cleared by the respiratory tract to prevent disease. The clearance mechanisms used by the lungs vary depending on the size of the particles. Larger particles become trapped by mucus secretions in the trachea, bronchi, and proximal bronchioles; these trapped particles are swept upward toward the pharynx by the collective beating of ciliated cells. The **finest particles** (<2 μm)

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Engulfment of inorganic dust causes **macrophage activation** and the release of a number of cytokines that induce pulmonary inflammation. Growth factors, including platelet-derived growth factor and insulin-like growth factor, are also released and stimulate fibroblasts to proliferate and produce collagen. This production results in **progressive interstitial lung fibrosis** that characterizes the pneumoconioses.

(Choices A and E) The largest dust particles become trapped in the upper airways (eg, nasal passages, pharynx) and are cleared through coughing and sneezing.

(Choice B) Immunologic memory can help with the clearance of previously encountered microorganisms but would not contribute to the removal of inorganic dust particles.

(Choice C) Mucociliary transport is the primary means of eliminating particles that lodge in the bronchi and bronchioles (typically, medium-sized particles).

Educational objective:
The pneumoconioses are diseases resulting from the inhalation of fine dust particles that reach the respiratory bronchioles and alveoli. Particles that lodge in this region are normally cleared by alveolar macrophages. High particulate burden can cause the excessive release of cytokines from macrophages, resulting in progressive pulmonary fibrosis.

Physiology	Pulmonary & Critical Care	Respiratory mucosa
Subject	System	Topic

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A 3-year-old boy is brought to the office with 5 days of productive cough and fever. Examination shows a tachypneic, ill-appearing child with rales over the right lower lung. Chest x-ray reveals right lower lobe pneumonia. The boy is admitted to the hospital for intravenous antibiotics. Review of his medical history shows 4 prior pneumonias, and his weight is at the third percentile. Further testing demonstrates high sweat chloride content, and genetic sequencing shows a mutation in a transmembrane protein. Which of the following best describes the dysfunctional transmembrane protein causing this patient's disease?

- A. ATP-gated
- B. Cyclic nucleotide-gated
- C. Mechanically gated
- D. Temperature-gated
- E. Voltage-gated

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- ✓ A. ATP-gated (51%)
- B. Cyclic nucleotide-gated (8%)
- C. Mechanically gated (8%)
- D. Temperature-gated (0%)
- E. Voltage-gated (30%)

Omitted
Correct answer
A

51%
Answered correctly

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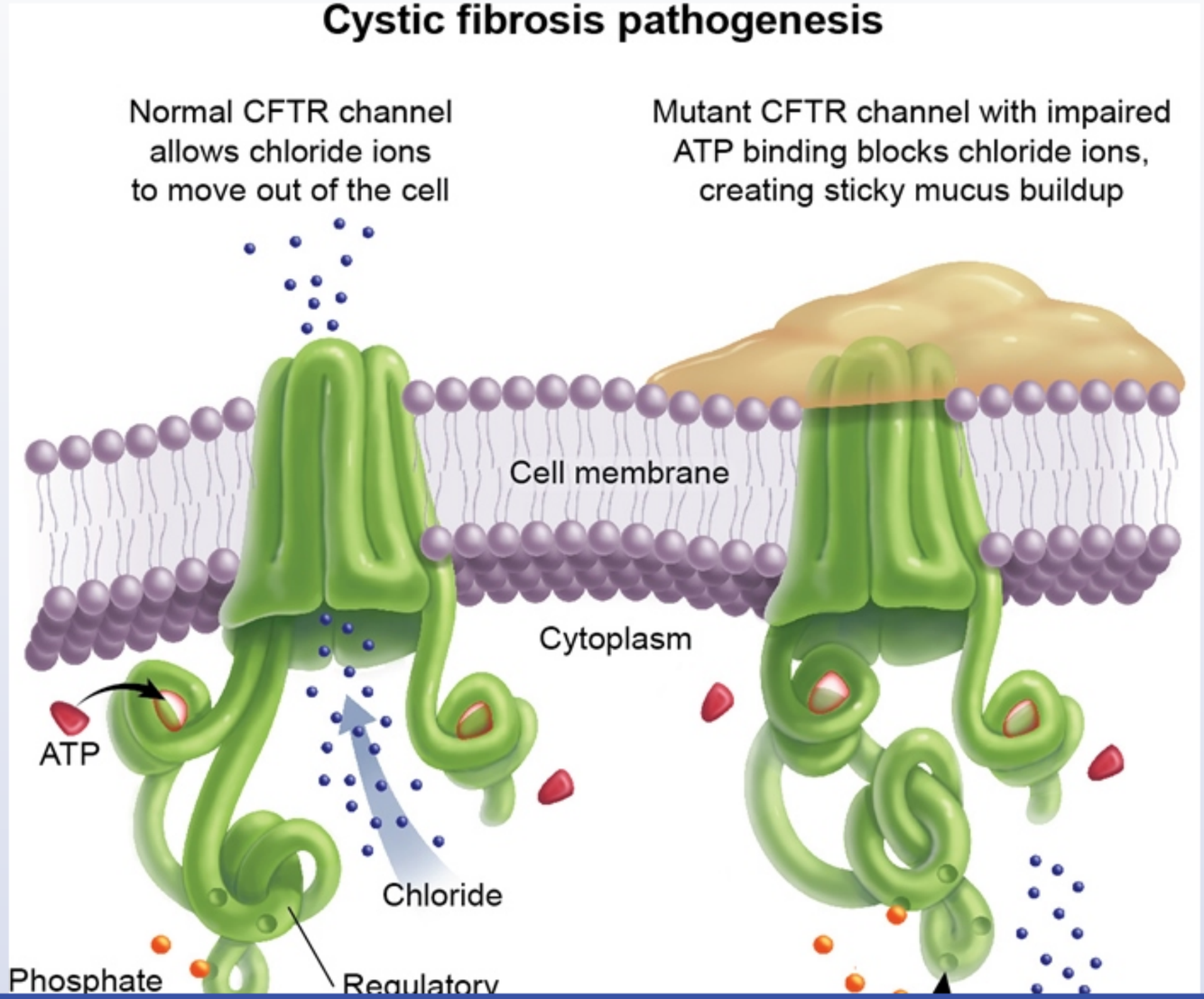
Explanation

Cystic fibrosis pathogenesis

Normal CFTR channel allows chloride ions

Mutant CFTR channel with impaired ATP binding blocks chloride ions,

Explanation



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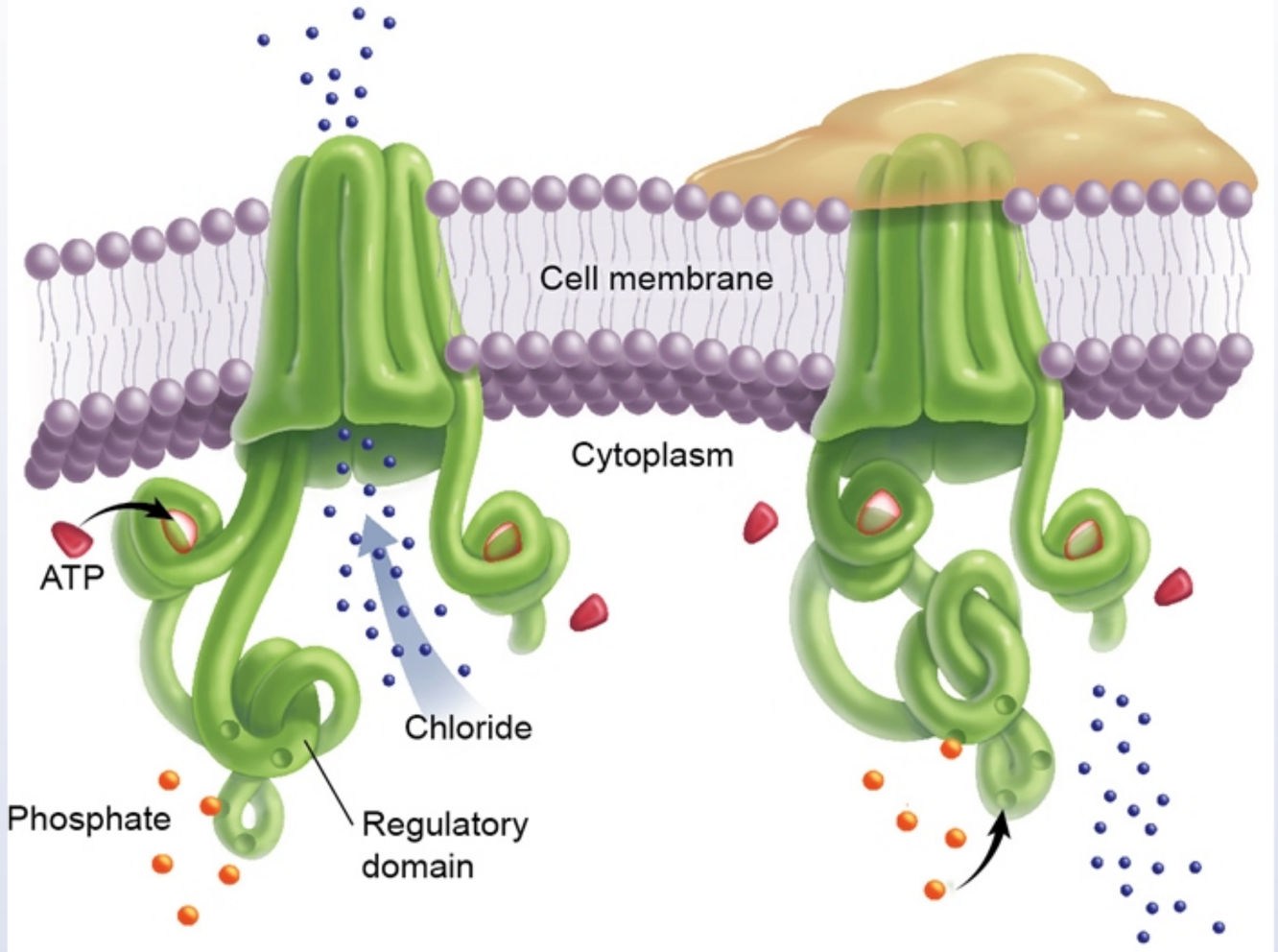

CFTR = cystic fibrosis transmembrane conductance regulator.

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Cystic fibrosis (CF) is an autosomal recessive disorder due to mutations (eg, ΔF508) in the **CF transmembrane conductance regulator (CFTR)** protein. The channel pore **opens** after binding of **2 ATP molecules**, allowing transport of chloride ions down the electrochemical gradient. The movement of chloride establishes a membrane potential that draws sodium and water across the membrane as well. By encouraging sodium

Cystic fibrosis (CF) is an autosomal recessive disorder due to mutations (eg, ΔF508) in the **CF transmembrane conductance regulator (CFTR)** protein. The channel pore **opens** after binding of **2 ATP molecules**, allowing transport of chloride ions down the electrochemical gradient. The movement of chloride establishes a membrane potential that draws sodium and water across the membrane as well. By encouraging sodium chloride and water transport across epithelial membranes, the CFTR **hydrates mucosal surfaces** in the airways and bowel. Mutations in the *CFTR* gene lead to intracellular protein degradation and decreased activity of the proteins that do reach the membrane. This leads to **thick mucus** on the lining of epithelial cells, which results in clinical manifestations of chronic cough, recurrent pneumonias, and pancreatic damage.

The normal CFTR protein also plays a role in the production of hypotonic sweat. In the eccrine gland, sweat is initially isotonic with the plasma, and normally sodium chloride is removed from the ductal lumen by CFTR. In the absence of functional CFTR, patients with CF cannot remove salt from their sweat and therefore have **elevated sweat chloride** and sodium levels. As early as the 17th century, increased mortality was recognized for children whose foreheads tasted salty. Today, the sweat chloride test is frequently used to screen for CF.

(Choice B) Cyclic nucleotide-gated ion channels are important for photoreceptor and olfactory receptor neurons. These nonselective channels are directly activated by cyclic nucleotides (eg, cyclic adenosine monophosphate [cAMP]). In contrast, CFTR channels are modulated by cAMP-dependent phosphorylation, but they are not directly gated by cAMP binding.

(Choice C) Mechanically gated (or stretch-activated) channels are ion channels that open in response to mechanical deformation of a cell membrane. Touch and hearing depend on mechanically activated channel transduction of mechanical force into electrochemical signals.

(Choice D) Temperature-gated ion channels open in response to heat and are responsible for human sensation of external temperature.

(Choice E) Voltage-gated ion channels open and close in response to changes in electrical membrane potential and are permeable to various ions. Congenital long QT syndrome is caused by a mutation in a voltage-gated potassium channel.

Educational objective:
Cystic fibrosis is an autosomal recessive disease caused by mutations in the CF transmembrane conductance regulator (*CFTR*) gene. The CFTR protein is a transmembrane ATP-gated chloride channel. Defects in CFTR result in thick, plugging mucous and elevated sodium and chloride levels in sweat.

References

- Targeting ion channels in cystic fibrosis.

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References

- Targeting ion channels in cystic fibrosis.
- Cystic fibrosis.

Physiology	Pulmonary & Critical Care	Cystic fibrosis
Subject	System	Topic

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A 36-year-old man comes to the office due to chronic, mild dyspnea and fatigue. The patient also says that his mind seems "foggy" all the time and he is not able to think clearly. He has no significant past medical history and does not take any medication. He lives a sedentary lifestyle and has smoked a half-pack of cigarettes a day for 5 years. Blood pressure is 140/85 mm Hg, pulse is 84/min, and respirations are 18/min. BMI is 32 kg/m^2. Lung auscultation is unremarkable. Chest x-ray is normal. Arterial blood gas analysis shows partial pressure of oxygen (PaO_2) is 66 mm Hg and partial pressure of carbon dioxide ($PaCO_2$) is 58 mm Hg. His estimated alveolar to arterial oxygen gradient is 10 mm Hg. Which of the following best explains this patient's laboratory findings?

- A. Chronic hypoventilation
- B. Decreased lung diffusing capacity
- C. Destruction of lung parenchyma
- D. Increased lung compliance
- E. Increased tissue oxygen consumption
- F. Right-to-left shunt

Submit

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- ✓ A. Chronic hypoventilation (64%)
- B. Decreased lung diffusing capacity (18%)
- C. Destruction of lung parenchyma (6%)
- D. Increased lung compliance (4%)
- E. Increased tissue oxygen consumption (1%)
- F. Right-to-left shunt (5%)

Omitted
Correct answer
A

64%
Answered correctly

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04/20/2020
Last Updated

Explanation

Causes of hypoxemia		

Causes of hypoxemia		
	Examples	**A-a gradient**
Reduced PiO_2	High altitude	Normal
Hypoventilation	CNS depression, morbid obesity	Normal
Diffusion limitation	Emphysema, ILD	Increased
V/Q mismatch*	Pulmonary embolism, pneumonia	Increased

*Caused by regional dead-space ventilation and/or intrapulmonary shunting.

A-a gradient = alveolar to arterial oxygen gradient; **ILD** = interstitial lung disease; **PiO_2** = partial pressure of inspired oxygen; **V/Q** = ventilation/perfusion ratio.

This patient with chronic fatigue, dyspnea, difficulty concentrating, **hypoxemia** (PaO_2 <75 mm Hg), and **hypercapnia** ($PaCO_2$ >45 mm Hg) in the setting of **obesity** (BMI >30 kg/m^2) likely has **obesity hypoventilation syndrome** (OHS). OHS results from physical restriction of lung expansion by excessive thoracic tissue mass. As such, the hypoventilation mostly results from **reduced tidal volume** and patients may have normal or increased respiratory rate. Most patients with OHS also have concomitant obstructive sleep apnea (OSA); unlike isolated OSA that involves hypoventilation only with sleep, OHS involves hypoventilation throughout the waking hours.

In healthy individuals, a normal alveolar to arterial (A-a) gradient ranges from 4-15 mm Hg, with older individuals having a gradient towards the higher end of normal. A **normal A-a gradient** indicates that the efficiency of gas exchange between the alveoli and the blood is intact; therefore, hypoxemia must result from low partial pressure of alveolar oxygen (PAO_2). Low PAO_2 can occur due to **alveolar hypoventilation** (eg, OHS, neuromuscular disease, central depression of respiratory drive) or inspiration of low partial pressure of oxygen at high altitude.

(Choices B and C) Destruction of lung parenchyma occurs with both emphysema and interstitial lung disease. This leads to disruption of the alveolar-capillary membrane and impaired diffusion capacity with an increased A-a gradient. In OHS, the lung parenchyma is undamaged and diffusion capacity is intact.

ratio.

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(Choice D) Although the lung parenchyma is unaffected in OHS, restricted expansion of the chest wall secondarily restricts lung expansion, effectively decreasing lung compliance.

(Choice E) Tissue oxygen consumption does increase with increased body mass, but it is a relatively minor factor and would not cause hypoxemia or hypercapnia in the absence of hypoventilation.

(Choice F) Right-to-left shunting (eg, Eisenmenger syndrome) results in hypoxemia with an elevated A-a gradient because a large percentage of cardiac output bypasses the alveolar capillaries and does not undergo gas exchange.

Educational objective:
Obesity hypoventilation syndrome commonly presents with chronic fatigue, dyspnea, and difficulty concentrating. Patients will have BMI >30 kg/m^2 and arterial blood gas while awake showing evidence of hypoventilation, including hypercapnia ($PaCO_2$ >45 mm Hg) and usually hypoxemia (PaO_2 <75 mm Hg). The expected alveolar to arterial oxygen gradient is normal (4-15 mm Hg) with hypoventilation.

References

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References

- Obesity hypoventilation syndrome: a state-of-the-art review.
- Chronic hypoventilation and its management.

Physiology	Pulmonary & Critical Care	Obesity hypoventilation syndrome
Subject	System	Topic

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A 63-year-old woman is hospitalized because of dyspnea on exertion and generalized fatigue. She has been hospitalized 3 times during the past year for heart failure exacerbations. Her other medical problems include essential hypertension for 20 years, myocardial infarction at the age of 58, and hypercholesterolemia. She has a 36-pack-year smoking history in addition to a 10-year history of alcohol abuse. Physical examination reveals tachycardia, distended neck veins, bilateral crackles on lung auscultation, a third heart sound on cardiac auscultation, and pedal edema. The appropriate therapy is initiated. On the third day of hospitalization, her hematocrit level increases to 50%, up from 44% on admission. An arterial blood gas analysis shows an arterial O_2 partial pressure (PaO_2) of 70 mm Hg. A ^{51}Cr-tagged red blood cell infusion indicates normal red blood cell mass. Which of the following is the most likely cause of this patient's polycythemia?

- A. Polycythemia vera
- B. Hypoxic erythrocytosis
- C. Renal disease
- D. Occult neoplasia
- E. Relative erythrocytosis

Submit

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- A. Polycythemia vera (3%)
- B. Hypoxic erythrocytosis (48%)
- C. Renal disease (5%)
- D. Occult neoplasia (1%)
- ✓ E. Relative erythrocytosis (41%)

Omitted
Correct answer
E

41%
Answered correctly

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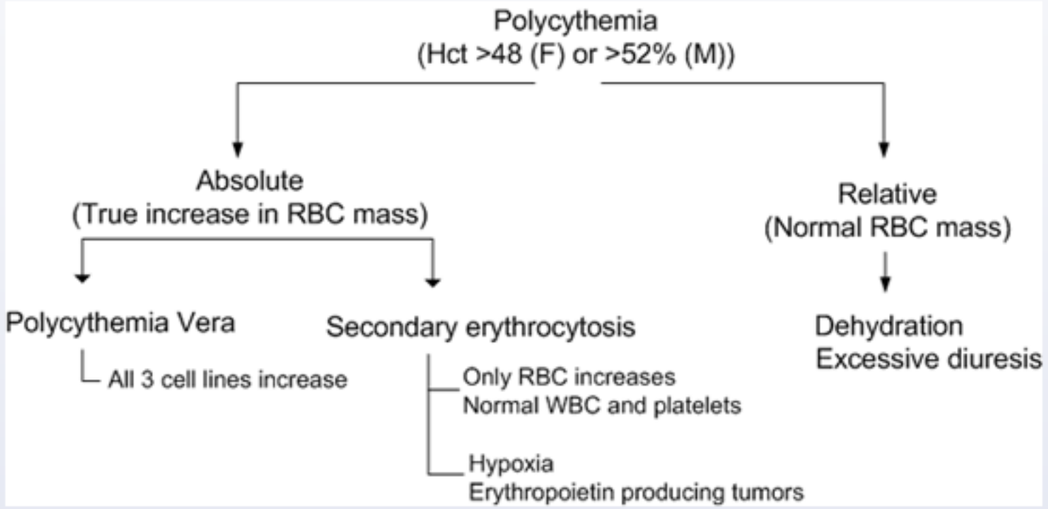
Explanation

Polycythemia (erythrocytosis) is defined as a hematocrit level > 52% in men and > 48% in women. It may be the result of a true increase in the red blood cell (RBC) mass (absolute erythrocytosis) or decrease in the plasma volume (relative erythrocytosis).

Explanation

Polycythemia (erythrocytosis) is defined as a hematocrit level > 52% in men and > 48% in women. It may be the result of a true increase in the red blood cell (RBC) mass (absolute erythrocytosis) or decrease in the plasma volume (relative erythrocytosis).



In a patient with erythrocytosis, the following tests can help determine the cause:

1. **Absolute versus relative erythrocytosis**: Hemoglobin and hematocrit levels cannot accurately differentiate these conditions. Direct measurement of the RBC mass is necessary. An increased total RBC mass indicates an absolute erythrocytosis; a normal RBC mass indicates a relative erythrocytosis. This patient does not have an increased RBC mass and is likely experiencing relative erythrocytosis due to aggressive diuretic therapy for her heart failure exacerbation.

2. **Primary versus secondary erythrocytosis**: Serum erythropoietin levels can be used to differentiate primary from secondary erythrocytosis. Primary erythrocytosis is associated with low erythropoietin levels and is caused by myeloproliferative disorders such as polycythemia vera. Secondary erythrocytosis is characterized by increased erythropoietin levels due to chronic hypoxia from high altitudes, smoking, or chronic obstructive pulmonary disease; or abnormal secretion by neoplastic or otherwise diseased tissues.

Erythropoietin producing tumors

In a patient with erythrocytosis, the following tests can help determine the cause:

1. **Absolute versus relative erythrocytosis**: Hemoglobin and hematocrit levels cannot accurately differentiate these conditions. Direct measurement of the RBC mass is necessary. An increased total RBC mass indicates an absolute erythrocytosis; a normal RBC mass indicates a relative erythrocytosis. This patient does not have an increased RBC mass and is likely experiencing relative erythrocytosis due to aggressive diuretic therapy for her heart failure exacerbation.

2. **Primary versus secondary erythrocytosis**: Serum erythropoietin levels can be used to differentiate primary from secondary erythrocytosis. Primary erythrocytosis is associated with low erythropoietin levels and is caused by myeloproliferative disorders such as polycythemia vera. Secondary erythrocytosis is characterized by increased erythropoietin levels due to chronic hypoxia from high altitudes, smoking, or chronic obstructive pulmonary disease; or abnormal secretion by neoplastic or otherwise diseased tissues.

3. **Hypoxic versus other causes of secondary erythrocytosis**: Measurement of the arterial oxygen saturation (SaO_2) is important to exclude hypoxemia as a cause of the erythrocytosis. $SaO_2 < 92\%$ ($PaO_2 < 65$ mm Hg) can cause secondary polycythemia. SaO_2 (measured as a percentage) should not be confused with PaO_2 (measured as a partial pressure in mm Hg).

(Choice A) Polycythemia vera is a myeloproliferative disorder associated with marked erythrocytosis and more modest increases in granulocytes and platelets. A low erythropoietin level is characteristic, along with increased RBC mass.

(Choice B) Hypoxia is a common cause of secondary erythrocytosis. $SaO_2 < 92\%$ ($PaO_2 < 65$ mm Hg) appears to be the threshold for the development of secondary erythrocytosis. This patient has hypoxemia above this threshold, an acute (< 3 day) increase in hematocrit, and normal RBC mass; none of these features are consistent with hypoxemia-induced erythrocytosis.

(Choices C and D) Occasionally, renal disease or occult neoplasia can cause secondary erythrocytosis due to abnormal erythropoietin production by the diseased tissue. Work-up will reveal an increased RBC mass and an increased erythropoietin level. However, chronic renal disease typically leads to decreased erythropoietin production.

Educational objective:
Erythrocytosis is defined as a hematocrit level > 52% in men and > 48% in women. Measurement of red blood cell mass is necessary to distinguish absolute from relative erythrocytosis. A normal red blood cell mass indicates plasma volume contraction as the cause of polycythemia.

smoking, or chronic obstructive pulmonary disease; or abnormal secretion by neoplastic or otherwise diseased tissues.

3. **Hypoxic versus other causes of secondary erythrocytosis**: Measurement of the arterial oxygen saturation (SaO_2) is important to exclude hypoxemia as a cause of the erythrocytosis. $SaO_2 < 92\%$ ($PaO_2 < 65$ mm Hg) can cause secondary polycythemia. SaO_2 (measured as a percentage) should not be confused with PaO_2 (measured as a partial pressure in mm Hg).

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Erythrocytosis is defined as a hematocrit level > 52% in men and > 48% in women. Measurement of red blood cell mass is necessary to distinguish absolute from relative erythrocytosis. A normal red blood cell mass indicates plasma volume contraction as the cause of polycythemia.

References

- Investigation of patients with polycythaemia.
- Oxygen desaturation in apparent and relative polycythaemia.

Physiology	Pulmonary & Critical Care	Polycythemia
Subject	System	Topic

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A 34-year-old man travels to Peru to participate in a mountain-climbing expedition. He has no prior medical problems and takes no medications. The patient does not use tobacco, alcohol, or illicit drugs. During his trip, he stays in a high-altitude camp in the mountains at over 4,000 m (13,000 ft) above sea level. After 2 days at the camp, the patient has blood drawn by the camp's physician while breathing ambient air. Which of the following sets of arterial blood gas values is most likely to be seen in this patient?

	pH	PaO_2 (mm Hg)	$PaCO_2$ (mm Hg)	Plasma HCO_3^- (mEq/L)
A.	7.22	62	60	24
B.	7.25	101	21	9
C.	7.38	96	40	23
D.	7.46	100	26	18
E.	7.48	60	29	21
F.	7.51	75	50	39

Submit

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	pH	PaO_2 (mm Hg)	$PaCO_2$ (mm Hg)	Plasma HCO_3^- (mEq/L)
A. (8%)	7.22	62	60	24
B. (2%)	7.25	101	21	9
C. (10%)	7.38	96	40	23
D. (19%)	7.46	100	26	18
✓ E. (53%)	7.48	60	29	21
F. (6%)	7.51	75	50	39

Omitted
Correct answer

53%
Answered correctly

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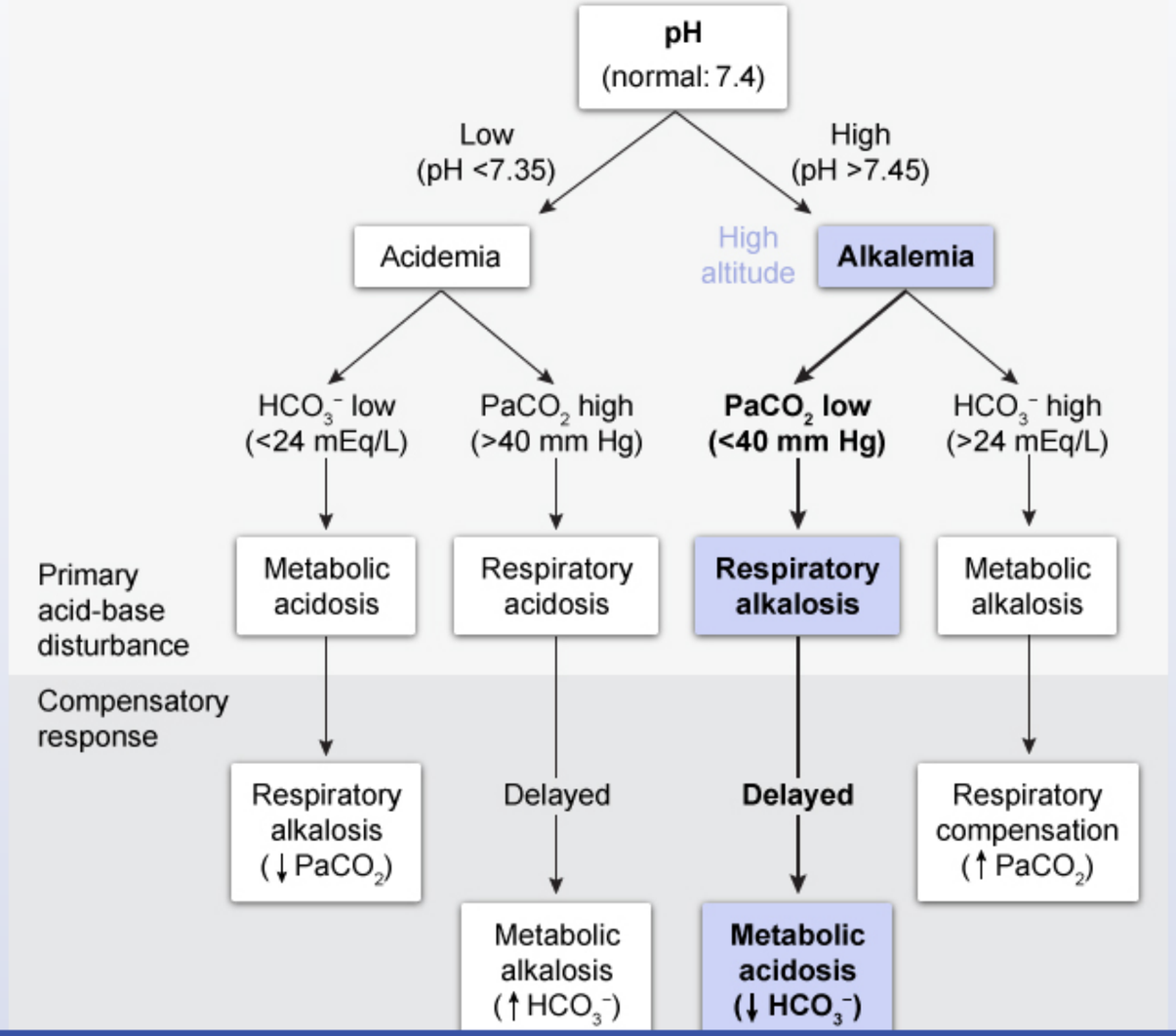
Arterial blood gas interpretation of acid-base disorders



HCO_3^- = bicarbonate; $PaCO_2$ = partial pressure of carbon dioxide in arterial blood.

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The partial pressure of inspired oxygen (PiO_2) is decreased at **high altitude**, meaning that fewer oxygen molecules are inspired with each breath. This leads to **hypoxemia** with a marked reduction in the arterial partial pressure of O_2 (PaO_2). Hypoxemia triggers chemoreceptors in the carotid bodies to stimulate ventilation, and with hyperventilation, there is **increased exhalation of CO_2**, leading to respiratory alkalosis. Over several days, the kidneys compensate by increasing bicarbonate (HCO_3^-) excretion to **decrease serum HCO_3^-** and help normalize pH.

Hypoxemia persists because the low PiO_2 allows hyperventilation to increase PaO_2 only slightly. Accordingly, the body makes several adjustments that improve O_2 delivery and O_2-carrying capacity to optimize O_2 use in the setting of persistently low PaO_2. These adjustments include:

- Increased 2,3-bisphosphoglycerate to encourage O_2 unloading in the tissues
- Increased angiogenesis via increased production of vascular endothelial growth factor
- Increased hemoglobin via increased production of erythropoietin

Therefore, in this individual who spent 2 days at high altitude, the expected arterial blood gas findings reflect **partially compensated respiratory alkalosis** (slightly elevated pH, low partial pressure of arterial CO_2 [$PaCO_2$], somewhat low HCO_3^-) and **persistent hypoxemia** (PaO_2 <75 mm Hg).

(Choice A) Low pH with high $PaCO_2$ indicates respiratory acidosis. Near-normal HCO_3^- is consistent with acute respiratory acidosis because there has been little time for renal metabolic compensation. Acute respiratory acidosis with hypoxemia can occur due to hypoventilation (eg, from opioid overdose).

(Choice B) Low pH with low HCO_3^- indicates metabolic acidosis. The low $PaCO_2$ reflects respiratory compensation via hyperventilation.

(Choice C) These values are close to approximate normal values: pH of 7.4, $PaCO_2$ of 40 mm Hg, and HCO_3^- of 24 mEq/L. This reflects an absence of acid-base disturbance.

(Choice D) Slightly elevated pH with low $PaCO_2$ and low HCO_3^- is consistent with chronic respiratory alkalosis with appropriate metabolic compensation. These acid-base findings are expected after >72 hours at high altitude (adequate time for full renal compensation); however, PaO_2 does not normalize.

(Choice E) High pH with high HCO_3^- indicates metabolic alkalosis. The elevated $PaCO_2$ represents respiratory compensation via

HCO_3^- = bicarbonate; $PaCO_2$ = partial pressure of carbon dioxide in arterial blood.

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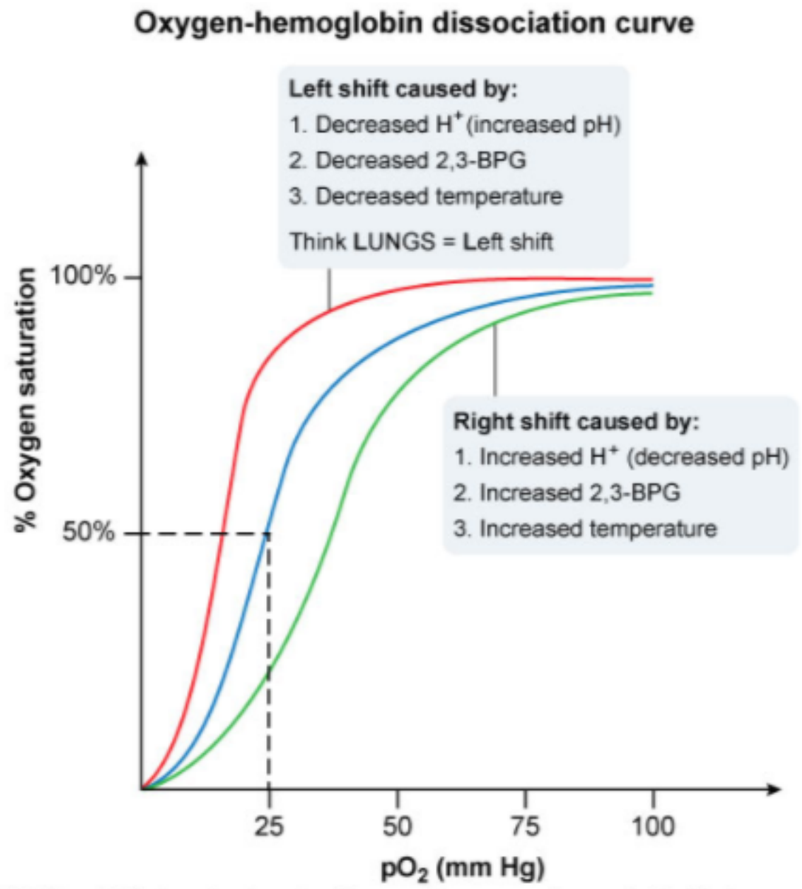

2,3-BPG = 2,3-bisphosphoglycerate; pO_2 = partial pressure of oxygen in the blood.

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(Choice F) High pH with high HCO_3^- indicates metabolic alkalosis. The elevated $PaCO_2$ represents respiratory compensation via

HCO_3^- = bicarbonate; $PaCO_2$ = partial pressure of carbon dioxide in arterial blood.

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(Choice F) High pH with high HCO_3^- indicates metabolic alkalosis. The elevated $PaCO_2$ represents respiratory compensation via

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Appropriate compensatory $PaCO_2$ or bicarbonate changes in acid-base disorders

Metabolic acidosis (acute or chronic)	Expected $PaCO_2$ = (1.5 × bicarbonate) + 8 ± 2 (Winters formula)
Metabolic alkalosis (acute or chronic)	~7 mm Hg ↑ in $PaCO_2$ per 10 mEq/L ↑ in bicarbonate
Respiratory acidosis (chronic only*)	~4 mEq/L ↑ in bicarbonate per 10 mm Hg ↑ in $PaCO_2$
Respiratory alkalosis (chronic only*)	~4 mEq/L ↓ in bicarbonate per 10 mm Hg ↓ in $PaCO_2$

*Compensation for respiratory disturbances is minimal in the acute setting. The full level of chronic compensation is achieved after ~72 hr. For simplicity, normal baseline $PaCO_2$ and bicarbonate should be considered 40 mm Hg and 24 mEq/L, respectively.

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Therefore, in this individual who spent 2 days at high altitude, the expected arterial blood gas findings reflect **partially compensated respiratory alkalosis** (slightly elevated pH, low partial pressure of arterial CO_2 [$PaCO_2$], somewhat low HCO_3^-) and **persistent hypoxemia** (PaO_2 <75 mm Hg).

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(Choice F) High pH with high HCO_3^- indicates metabolic alkalosis. The elevated $PaCO_2$ represents respiratory compensation via hypoventilation. Such findings can occur with excessive vomiting or overuse of diuretics.

Educational objective:
At high altitude, the low partial pressure of inspired oxygen (PiO_2) leads to hypoxemia that triggers hyperventilation with increased exhalation of CO_2 and resulting respiratory alkalosis. The kidneys compensate by increasing bicarbonate (HCO_3^-) excretion to decrease serum HCO_3^- and help normalize pH. Hypoxemia persists, but physiologic adjustments take place to improve O_2 use.

References

- The physiological effects of hypobaric hypoxia versus normobaric hypoxia: a systematic review of crossover trials.

Physiology	Pulmonary & Critical Care	High altitude illness
Subject	System	Topic

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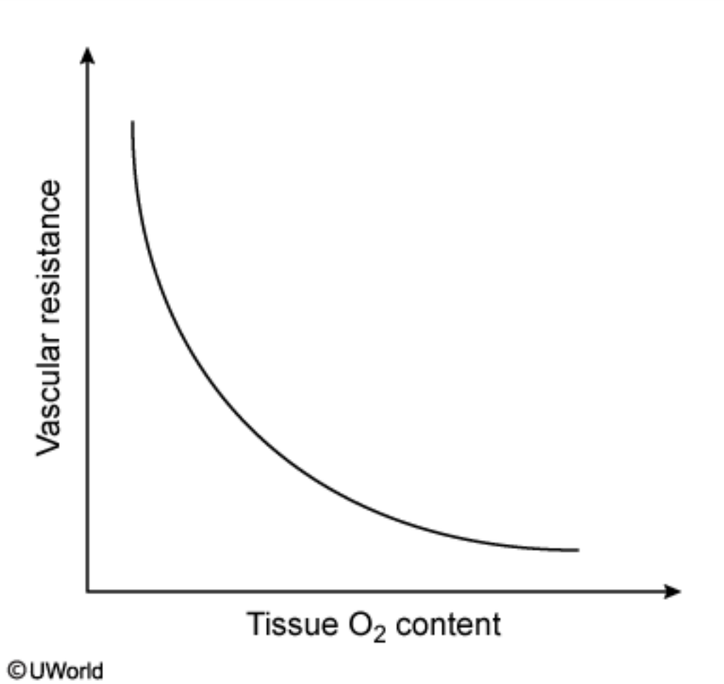
A researcher is conducting an experiment to determine factors affecting vascular resistance. Experiment animals are anesthetized, intubated, and attached to a controlled ventilation system. A catheter is placed into a small artery in various organs in each animal. The catheter is connected to a manometer for recording pressure and to an oximeter for continuous recording of oxygen saturation. The fraction of inspired oxygen is gradually changed, and arteriolar resistance is calculated from the manometer readings at regular intervals. The results shown below were most likely obtained from which of the following organs?



A. Brain

B. Heart

C. Kidneys

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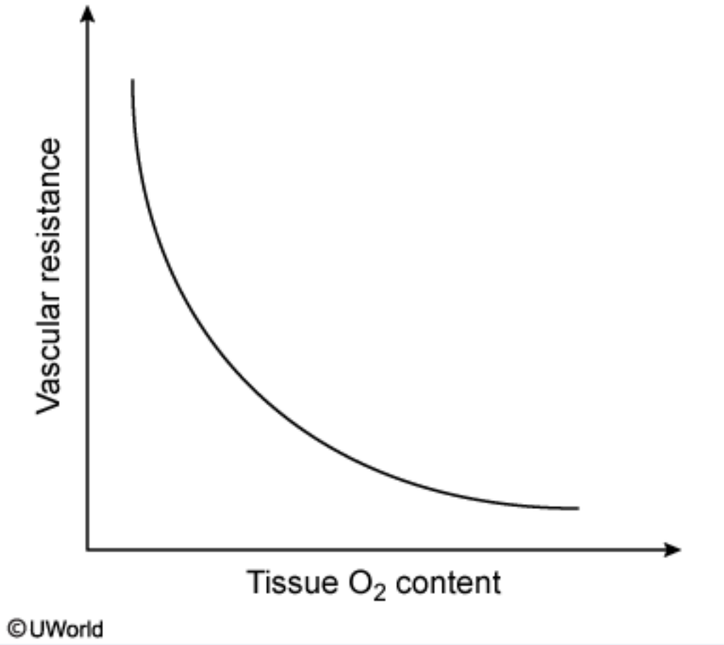

A. Brain

B. Heart

C. Kidneys

D. Lungs

E. Small intestine

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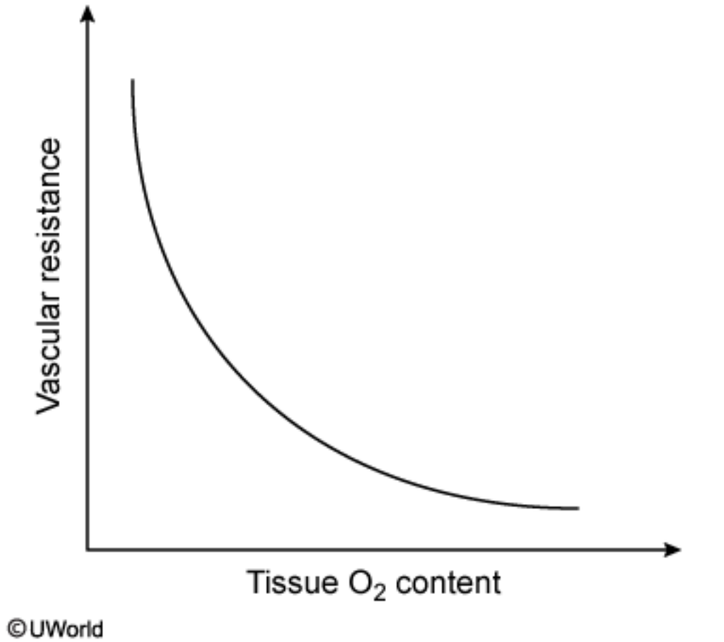

A. Brain (10%)

B. Heart (5%)

C. Kidneys (4%)

✓ D. Lungs (77%)

E. Small intestine (2%)

Omitted
Correct answer

77%
Answered correctly

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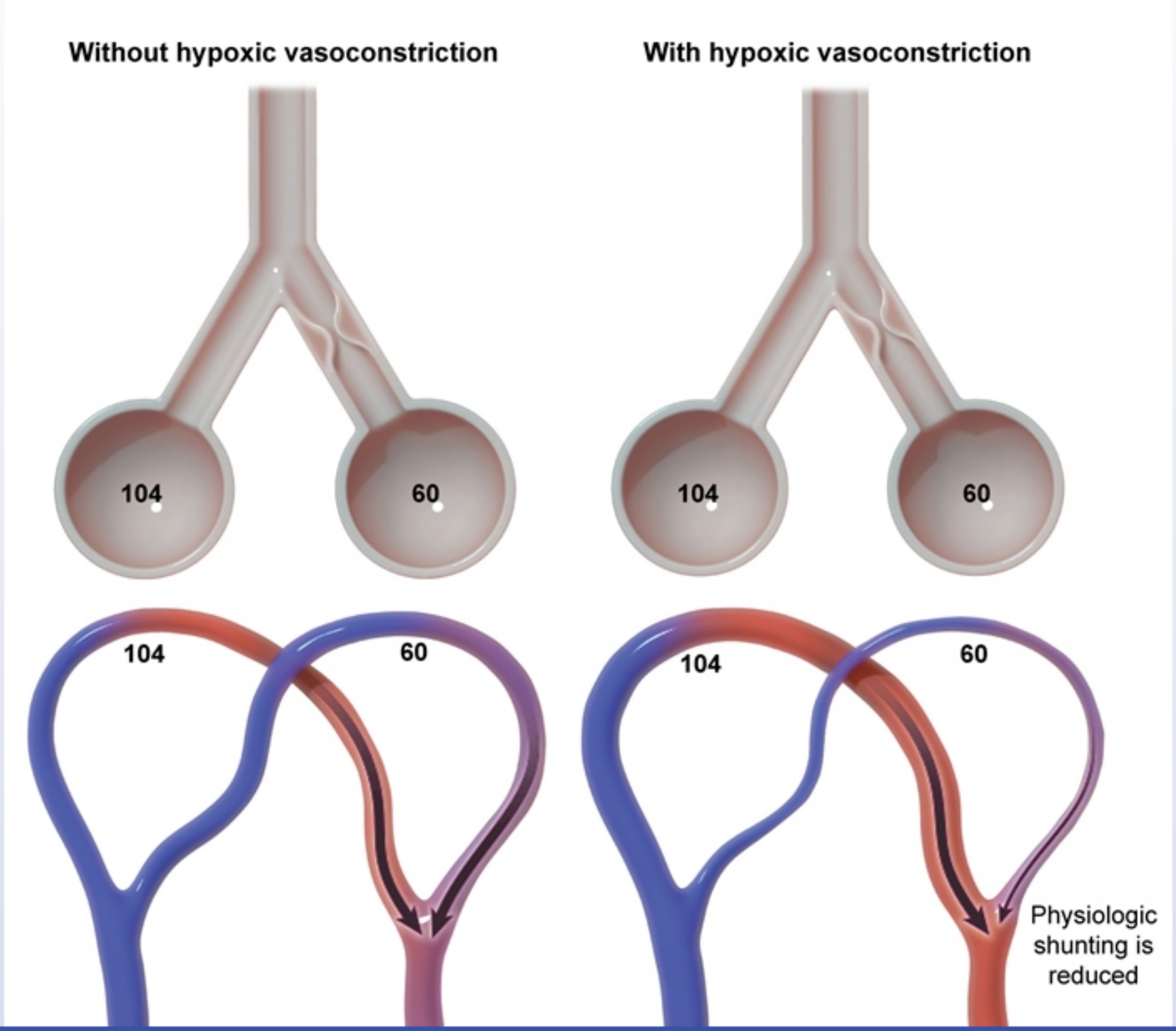

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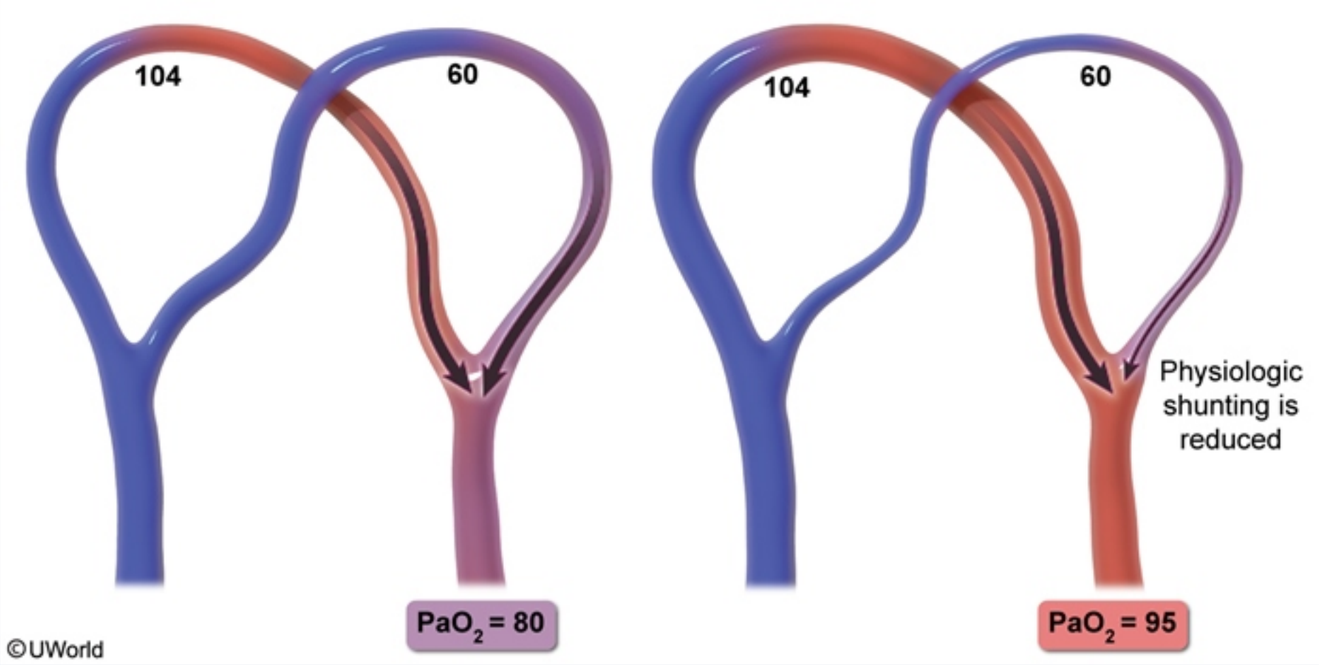

This graph depicts a vascular bed in which arterial/arteriolar resistance increases as the tissue O_2 content decreases. This response is unique to the **pulmonary vasculature**, in which **hypoxic vasoconstriction** occurs to divert blood flow away from underventilated lung regions and toward well-ventilated lung areas. This phenomenon **improves ventilation-perfusion mismatch** by decreasing physiologic shunting in poorly ventilated alveoli, leading to overall more **efficient gas exchange**. The relationship between hypoxia and vascular resistance is reversed throughout the rest of the body, ensuring that hypoxic organs and tissues receive increased blood flow.

(Choice A) Although the cerebral circulation is more sensitive to blood CO_2 levels (small degrees of hypercapnia lead to vasodilation), hypoxia causes significant arteriolar dilation when the partial pressure of oxygen (PO_2) falls below 50 mm Hg.

(Choice B) In the coronary vasculature, subendocardial blood flow is mediated by the local tissue PO_2, adenosine, prostacyclin, and nitric oxide. Decreased tissue PO_2 promotes vasodilation of arterioles in the myocardium.

(Choice C) A large increase in sympathetic tone may cause vasoconstriction of the renal vasculature, but hypoxia does not have this effect.

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(Choice C) A large increase in sympathetic tone may cause vasoconstriction of the renal vasculature, but hypoxia does not have this effect.

(Choice E) Parasympathetic-induced intestinal vasodilation occurs in response to digestive chyme passing over intestinal mucosa. Sympathetic tone (not hypoxia) plays a large role in the splanchnic vasoconstriction that occurs with exercise or significant hypovolemia.

Educational objective:
The pulmonary vascular bed is unique in that tissue hypoxia results in a vasoconstrictive response. Such hypoxic vasoconstriction occurs in the small muscular pulmonary arteries to divert blood flow away from underventilated lung regions and toward well-ventilated lung areas to minimize ventilation-perfusion mismatch, leading to more efficient overall gas exchange.

References

- Hypoxic pulmonary vasoconstriction in humans.
- Hypoxic pulmonary vasoconstriction.

Physiology	Pulmonary & Critical Care	Pulmonary Arterial Hypertension
Subject	System	Topic

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A 32-year-old woman is brought to the emergency department after being stuck in a malfunctioning elevator for 45 minutes. The patient says she felt extremely anxious in the closed space of the elevator and experienced dizziness, shortness of breath, generalized weakness, and blurred vision. She has no other medical conditions and takes no medications. She does not use tobacco, alcohol, or illicit drugs. Which of the following is the most likely cause of this patient's symptoms?

A. Decreased arterial partial pressure of CO_2

B. Decreased arterial partial pressure of O_2

C. Decreased arterial pH

D. Decreased arterial total O_2 content

E. Increased alveolar-arterial O_2 gradient

F. Increased arterial lactic acid content

Submit

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- ✓ A. Decreased arterial partial pressure of CO_2 (69%)
- B. Decreased arterial partial pressure of O_2 (11%)
- C. Decreased arterial pH (7%)
- D. Decreased arterial total O_2 content (6%)
- E. Increased alveolar-arterial O_2 gradient (2%)
- F. Increased arterial lactic acid content (1%)

Omitted
Correct answer
A

69%
Answered correctly

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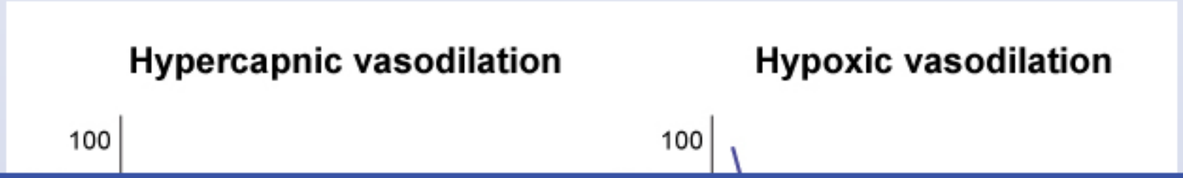
Explanation



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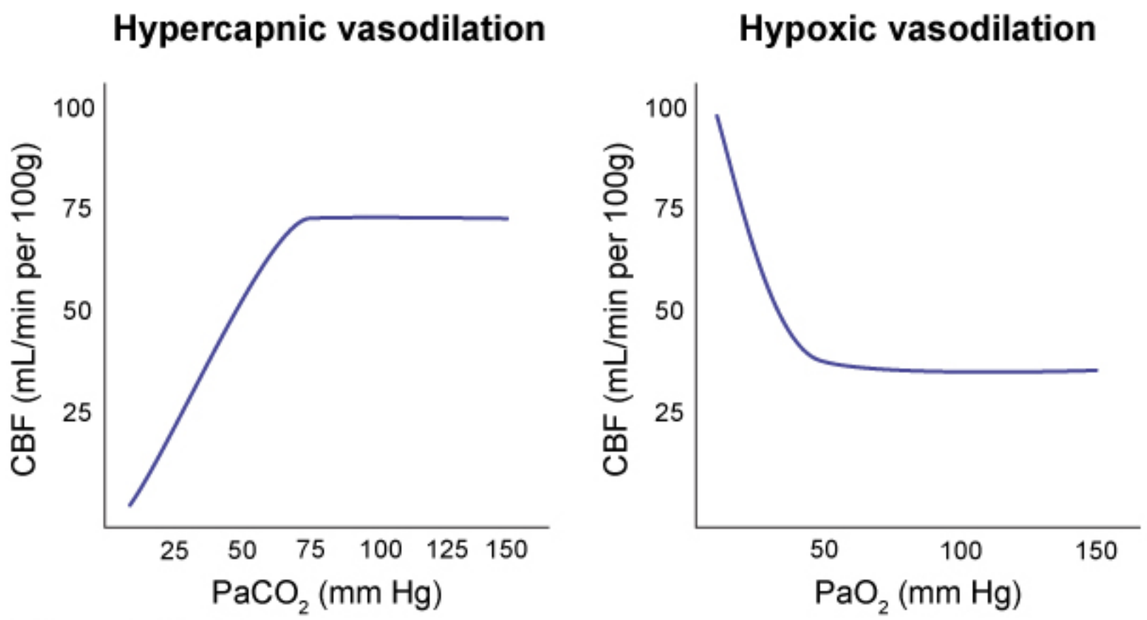

CBF = cerebral blood flow.

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This patient most likely had a panic attack while trapped in the elevator. Panic attacks are typically accompanied by **hyperventilation** with a resulting **decrease in arterial partial pressure of CO_2** ($PaCO_2$). This hypocapnia can cause **decreased cerebral perfusion** with consequent neurologic sequelae, including generalized weakness, blurred vision, presyncope (ie, dizziness, lightheadedness), and syncope.

Cerebral blood flow (CBF) remains relatively constant over a wide range of perfusion pressures (cerebrovascular autoregulation) and is mainly influenced by arterial blood gas levels, particularly changes in $PaCO_2$. Hypercapnia triggers an increase in CBF (to aid in removal of toxins), and hypocapnia triggers a decrease in CBF. In fact, because hypocapnia decreases CBF, mechanically ventilated patients with cerebral edema are often hyperventilated to decrease intracranial pressure and help prevent brain herniation.

CBF is less sensitive to the arterial partial pressure of oxygen (PaO_2). PaO_2 has little influence on CBF until the level drops below 50 mm Hg, at which point a rapid increase in CBF is triggered.

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(Choices B and D) The total blood O_2 content is predominantly made up of hemoglobin-bound O_2 (determined by the blood hemoglobin level and PaO_2) plus a small contribution of dissolved O_2. Hyperventilation increases the alveolar partial pressure of O_2 and should somewhat increase (rather than decrease) both PaO_2 and total blood O_2 content.

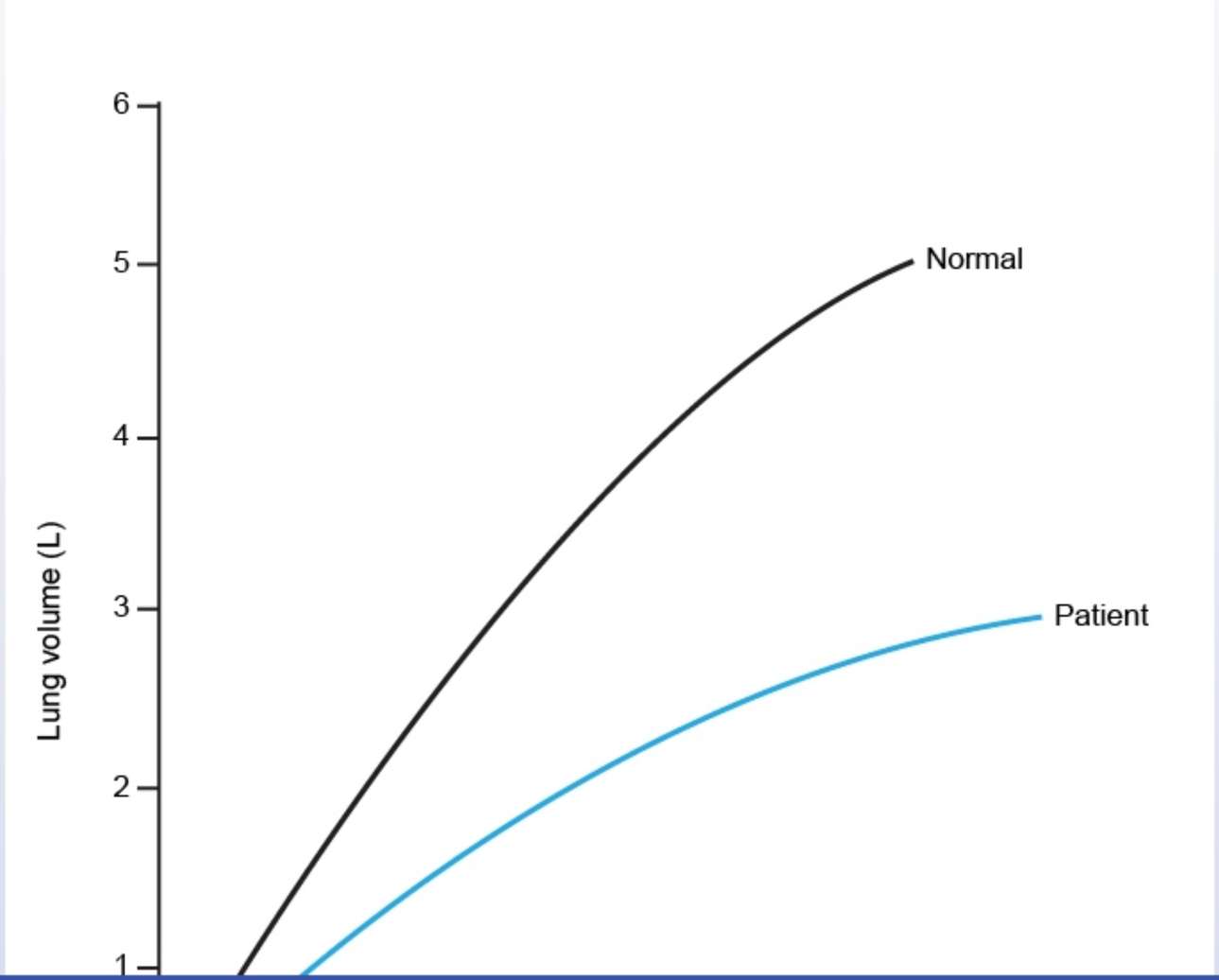
(Choice C) Hyperventilation produces respiratory alkalosis, marked by an increase in arterial pH.

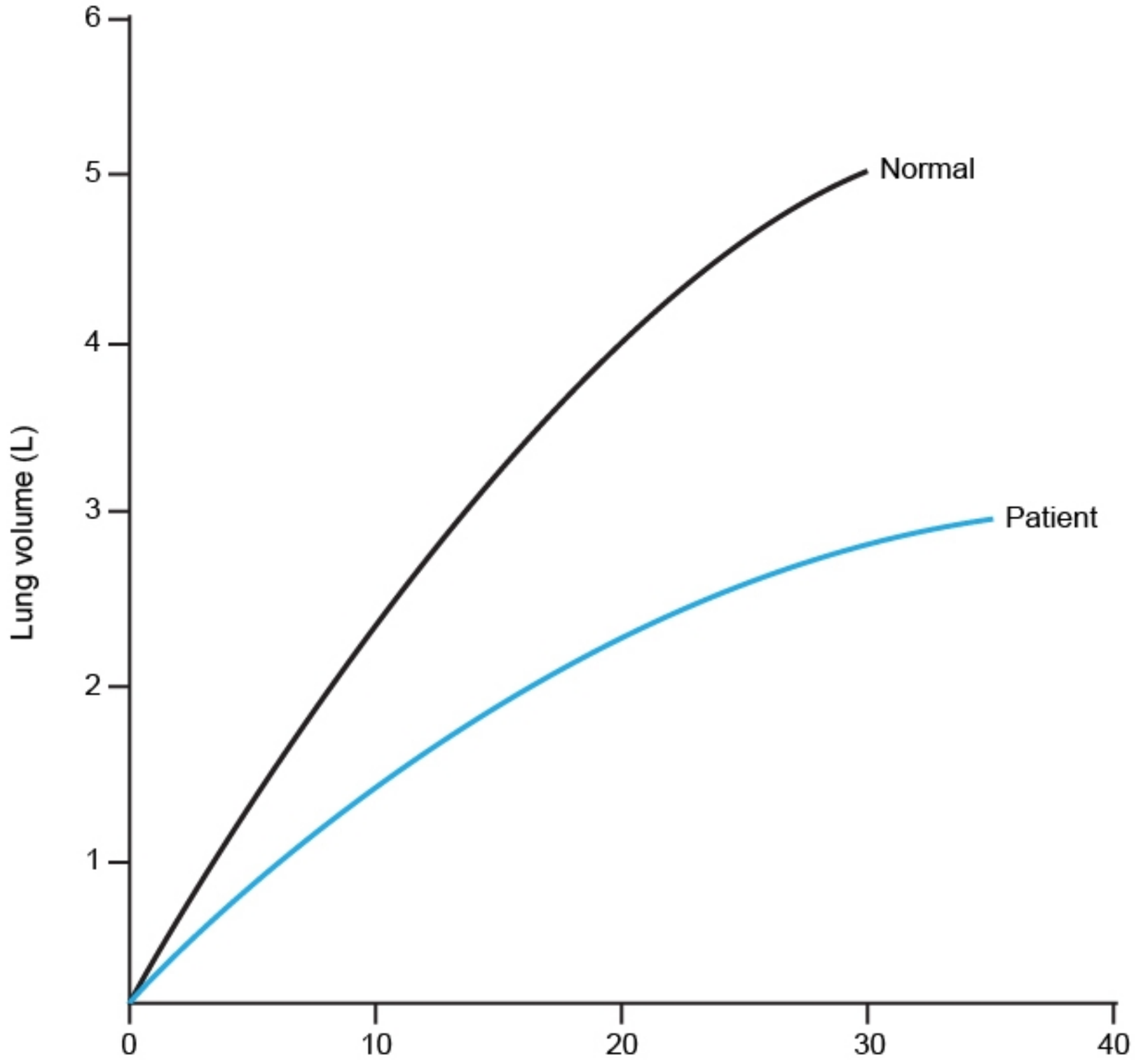
(Choice E) Disturbances that increase the alveolar-arterial O_2 gradient include V/Q mismatch (eg, pulmonary embolism), diffusion limitation, and right-to-left shunting (eg, Eisenmenger syndrome). Changes in ventilation rate (ie, hypo- or hyperventilation) have no effect on the alveolar-arterial O_2 gradient.

(Choice F) Increased arterial lactic acid content is a sign of tissue hypoxia (eg, due to sepsis or ischemia), which is unlikely in the setting of hyperventilation from a panic attack.

Educational objective:
Panic attacks are typically accompanied by hyperventilation, leading to hypocapnia. Cerebral blood flow is directly related to the arterial partial pressure of CO_2; therefore, hypocapnia can lead to reduced cerebral blood flow and symptoms of cerebral hypoperfusion (eg, blurred vision, dizziness, lightheadedness).

A 43-year-old patient comes to the physician due to dyspnea. The black curve shown below represents the pressure/volume relationship in normal lung tissue. The blue curve represents the pressure/volume relationship in the patient's lung tissue.




Lung volume (L)
6
5
4
3
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0
10
20
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40
Normal
Patient

1
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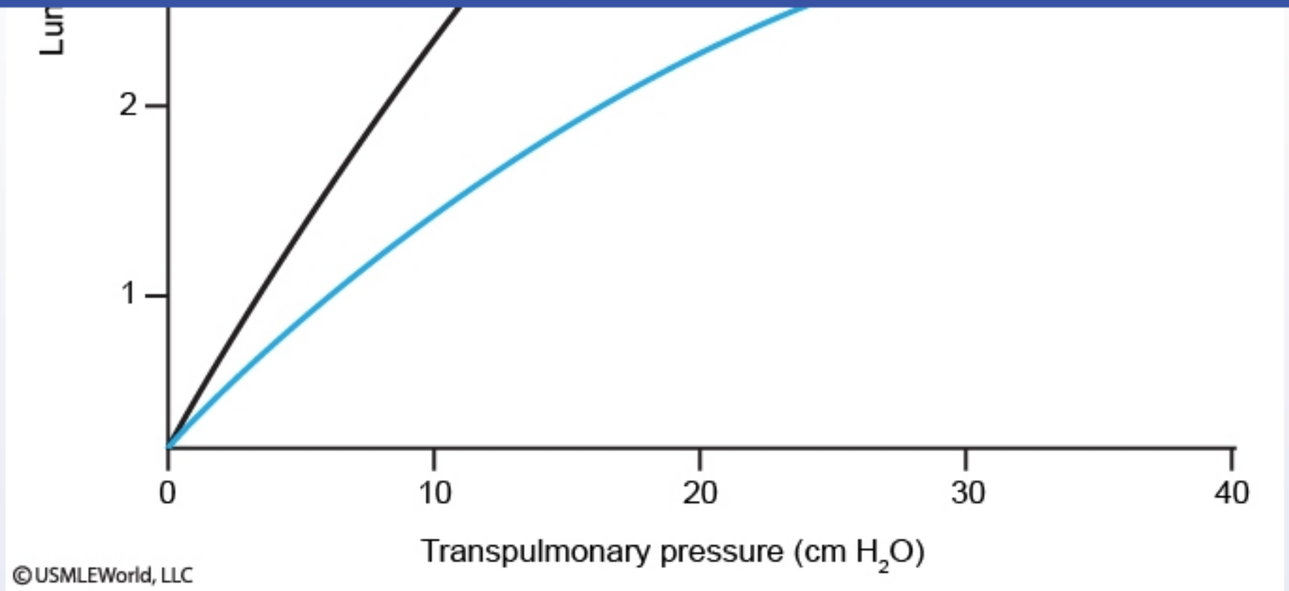
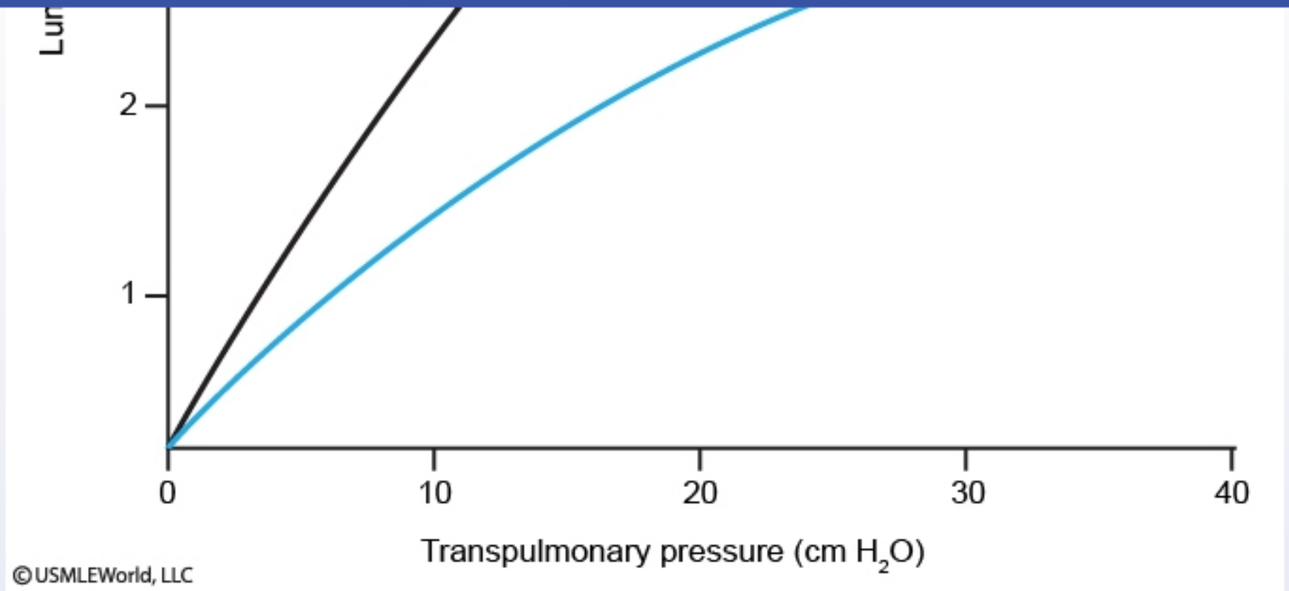


Which of the following is the most likely cause of this patient's symptoms?

- A. Alpha-1 antitrypsin deficiency
- B. Bronchial asthma
- C. Fibromyalgia
- D. Idiopathic pulmonary arterial hypertension
- E. Pulmonary fibrosis

Submit



Which of the following is the most likely cause of this patient's symptoms?

- A. Alpha-1 antitrypsin deficiency (4%)
- B. Bronchial asthma (2%)
- C. Fibromyalgia (0%)
- D. Idiopathic pulmonary arterial hypertension (1%)
- ✓ E. Pulmonary fibrosis (90%)

Omitted
Correct answer

90%
Answered correctly

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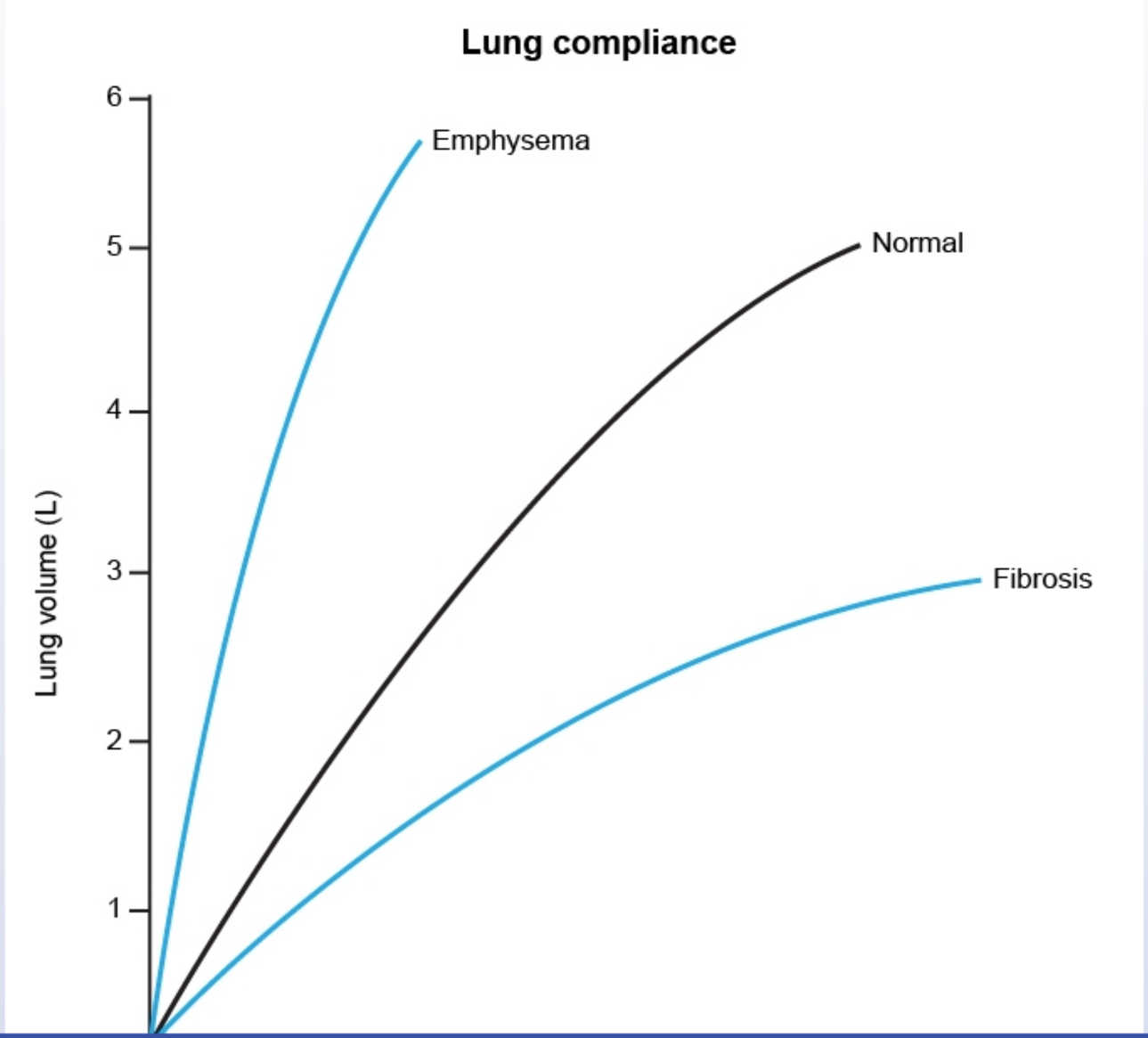
Last Updated


Lung compliance
Lung volume (L)
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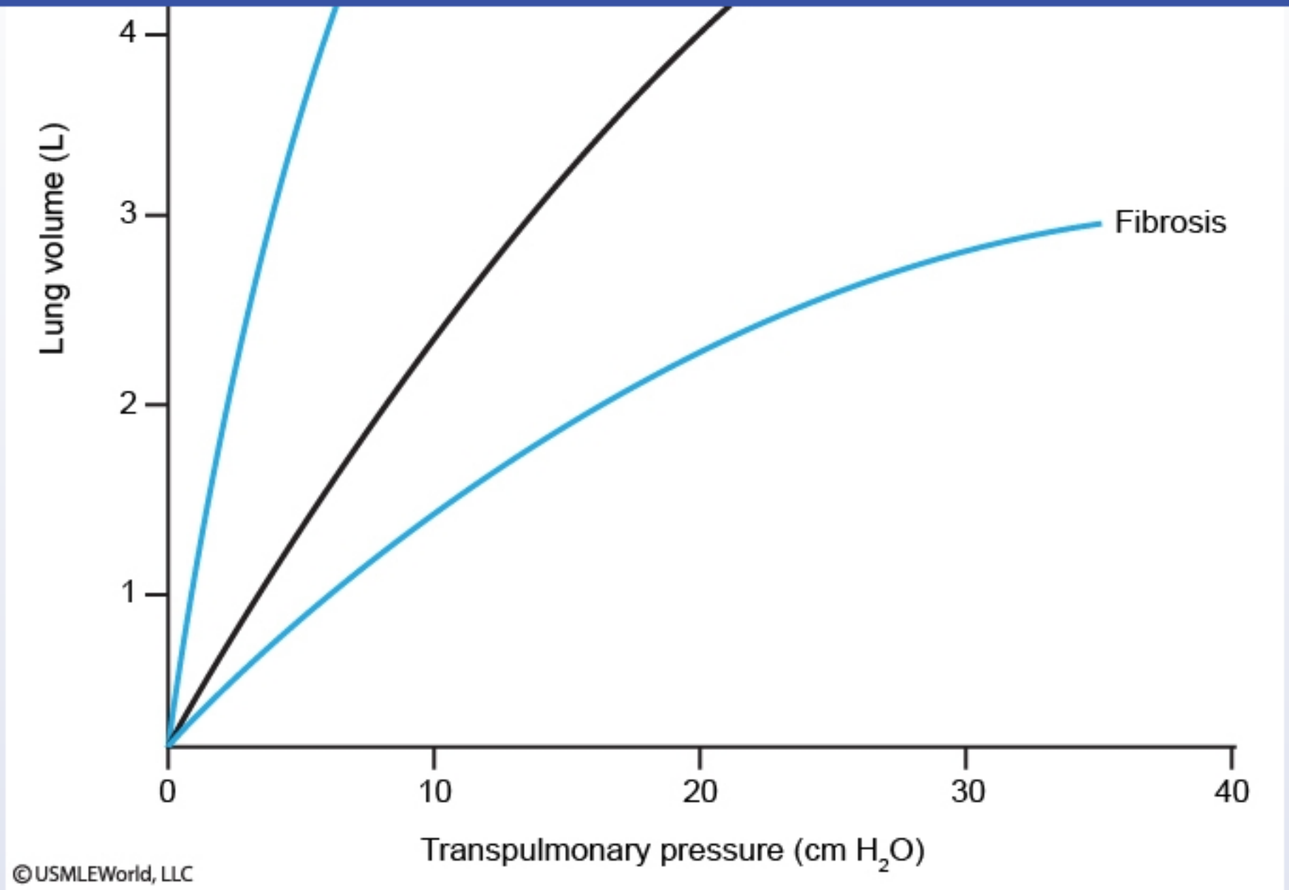
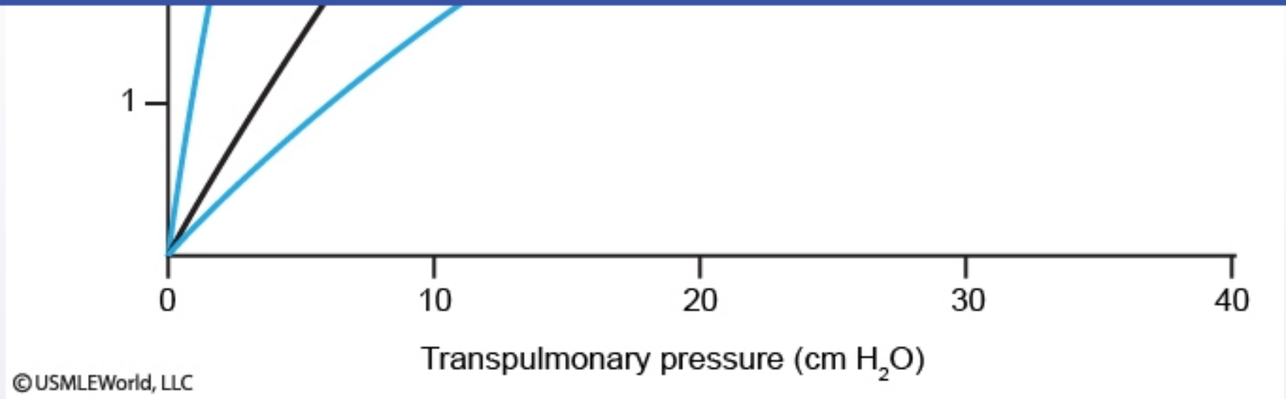
Emphysema
Normal
Fibrosis



The pressure/volume relationship in this patient's lungs depicts dramatically **reduced compliance** (ie, for any given volume the pressure will be significantly increased). Reduced pulmonary parenchymal compliance is the hallmark of **pulmonary fibrosis**.

(Choice A) Alpha-1 antitrypsin deficiency causes panacinar emphysema and liver cirrhosis. In **emphysema**, the lung parenchyma has **increased compliance**.

(Choice B) Asthma decreases peak expiratory flow rates and FEV_1 during pulmonary function testing, but it does not decrease lung compliance.



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(Choice A) Alpha-1 antitrypsin deficiency causes panacinar emphysema and liver cirrhosis. In **emphysema**, the lung parenchyma has **increased compliance**.

(Choice B) Asthma decreases peak expiratory flow rates and FEV_1 during pulmonary function testing, but it does not decrease lung compliance.

(Choice C) Fibromyalgia causes diffuse chronic axial musculoskeletal pain and tenderness. The lung parenchyma is normal.

(Choice D) Idiopathic pulmonary arterial hypertension does not significantly affect lung compliance.

Educational objective:
Reduction in the slope of the curve depicting lung volume versus distending pressure indicates decreased lung compliance (the hallmark of pulmonary fibrosis).

Physiology	Pulmonary & Critical Care	Interstitial lung disease
Subject	System	Topic

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A 43-year-old man is brought to the emergency department after being found unresponsive by his wife. She says he was in his usual state of health when she left home a few hours ago. The patient has a history of depression and type 2 diabetes mellitus. He was recently laid off from work. Blood pressure is 100/60 mm Hg and pulse is 64/min. On physical examination, the patient is responsive to deep sternal rub and has mildly dry mucous membranes. Arterial blood gas analysis reveals the following:

pH	7.22
$PaCO_2$	60 mm Hg
HCO_3^-	24 mEq/L

Which of the following is the most likely current acid-base status in this patient?

- A. Metabolic acidosis with respiratory compensation
- B. Metabolic alkalosis with respiratory compensation
- C. Respiratory acidosis with renal compensation
- D. Respiratory alkalosis with renal compensation
- E. Uncompensated metabolic acidosis
- F. Uncompensated respiratory acidosis

Submit

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pH	7.22
$PaCO_2$	60 mm Hg
HCO_3^-	24 mEq/L

Which of the following is the most likely current acid-base status in this patient?

- A. Metabolic acidosis with respiratory compensation (3%)
- B. Metabolic alkalosis with respiratory compensation (0%)
- C. Respiratory acidosis with renal compensation (8%)
- D. Respiratory alkalosis with renal compensation (0%)
- E. Uncompensated metabolic acidosis (4%)
- ✓ F. Uncompensated respiratory acidosis (82%)

Omitted
Correct answer
F

82%
Answered correctly

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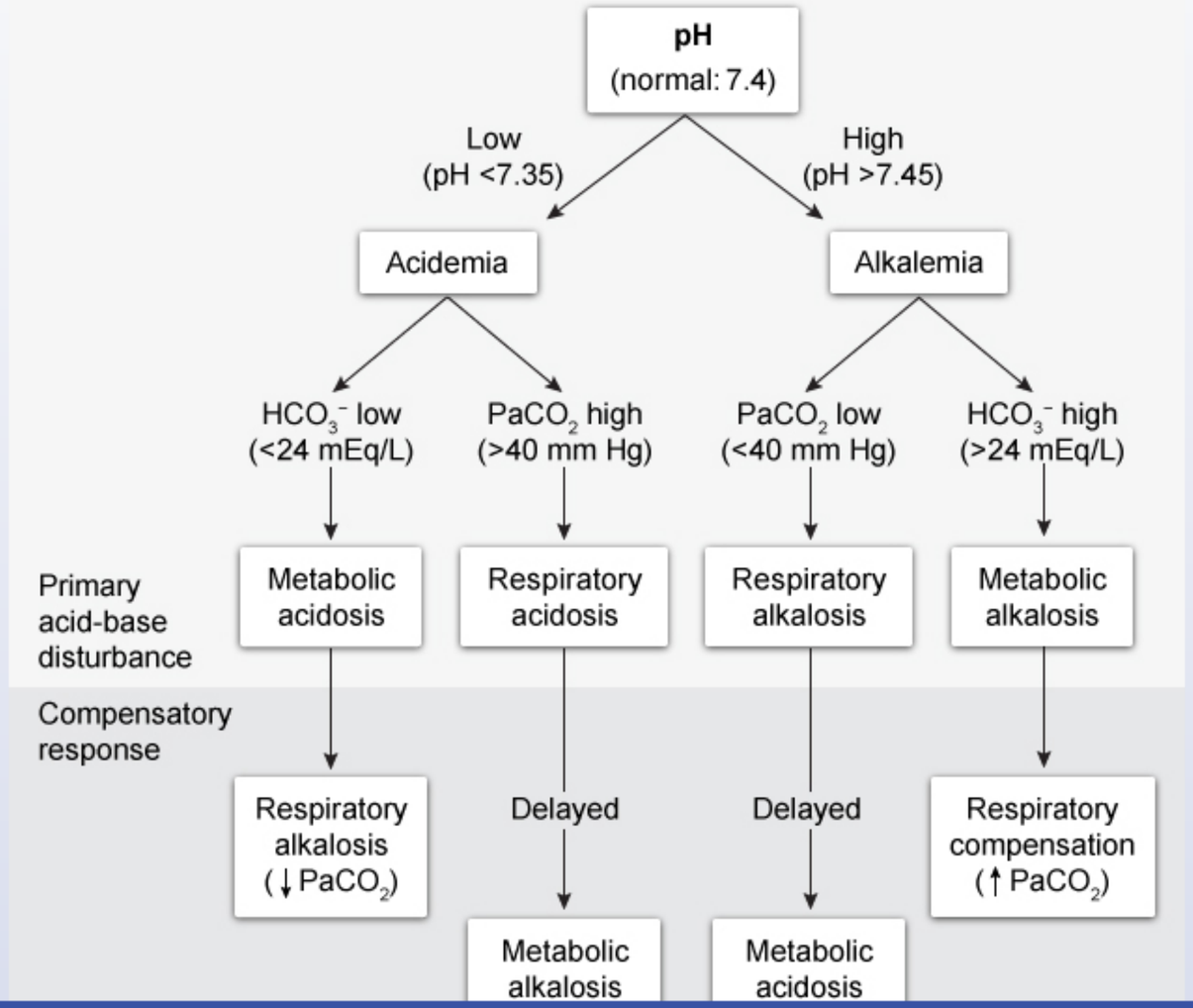
Arterial blood gas interpretation of acid-base disorders



HCO_3^- = bicarbonate, $PaCO_2$ = partial pressure of carbon dioxide in arterial blood.

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The assessment of an arterial blood gas follows a stepwise process:

1. Evaluate the **pH** (normal: 7.4): A value <7.35 signifies acidosis whereas a value >7.45 indicates alkalosis. This patient has an arterial blood pH of 7.22, which is consistent with **acidosis**.
2. Identify the **primary process**: Differentiate respiratory from metabolic processes by determining the $PaCO_2$ (normal: 40) and HCO_3^- (normal: 24).
   - Respiratory acidosis occurs due to the retention of CO_2 in the lungs and presents with a low pH and a high $PaCO_2$.
   - Metabolic acidosis develops due to depletion of HCO_3^- and is characterized by a low pH and a low HCO_3^-.

   This patient has a pH of 7.22 (low) and a $PaCO_2$ of 60 mm Hg (high), which is consistent with **respiratory acidosis**.
3. Identify compensation: Because increased $PaCO_2$ leads to an increased hydrogen ion concentration in the body, the kidneys begin to compensate by increasing resorption of HCO_3^- to help buffer the excess acid. The **renal compensation** begins after several hours and takes several days to complete. After approximately 72 hours, the expected compensatory increase in HCO_3^- is approximately 4 mEq/L for every 10 mm Hg elevation in $PaCO_2$.

This patient has a HCO_3^- of 24 mEq/L, which is normal and indicates **respiratory acidosis without compensation**. Causes of respiratory acidosis without compensation include any disorder that causes **acute hypoventilation** (eg, opioid overdose with depression of respiratory drive).

(Choices A and E) Metabolic acidosis is indicated by low pH and low serum HCO_3^-. The respiratory compensation involves hyperventilation to breathe off CO_2 and help increase pH. Respiratory compensation for metabolic disturbances begins right away and is usually maximized within hours; therefore, full (or nearly full) compensation is expected in both the acute and chronic setting unless the patient's breathing is compromised.

(Choice B) Metabolic alkalosis is indicated by high pH and high HCO_3^-. The respiratory compensation involves hypoventilation to retain CO_2 and decrease pH.

(Choice C) This patient's low pH and high $PaCO_2$ are consistent with respiratory acidosis, but the normal HCO_3^- indicates that renal compensation has not yet occurred.

This patient has a pH of 7.22 (low) and a $PaCO_2$ of 60 mm Hg (high), which is consistent with **respiratory acidosis**.

3. Identify compensation: Because increased $PaCO_2$ leads to an increased hydrogen ion concentration in the body, the kidneys begin to compensate by increasing resorption of HCO_3^- to help buffer the excess acid. The **renal compensation** begins after several hours and takes several days to complete. After approximately 72 hours, the expected compensatory increase in HCO_3^- is approximately 4 mEq/L for every 10 mm Hg elevation in $PaCO_2$.

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(Choice C) This patient's low pH and high $PaCO_2$ are consistent with respiratory acidosis, but the normal HCO_3^- indicates that renal compensation has not yet occurred.

(Choice D) Respiratory alkalosis is indicated by high pH and low $PaCO_2$. The metabolic compensation involves increased HCO_3^- excretion by the kidneys to help decrease pH and requires approximately 72 hours to complete.

Educational objective:
Respiratory acidosis presents with low pH and high $PaCO_2$. HCO_3^- initially remains near normal but becomes elevated over several days as renal compensation develops.

Physiology	Pulmonary & Critical Care	Respiratory acidosis
Subject	System	Topic

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This patient has a pH of 7.22 (low) and a $PaCO_2$ of 60 mm Hg (high), which is consistent with **respiratory acidosis**.

3. Identify compensa
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(Choice B) Metabolic al
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(Choice C) This patient'
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(Choice D) Respiratory
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Educational objective:
Respiratory acidosis pres
compensation develops.

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Exhibit Display

Appropriate compensatory $PaCO_2$ or bicarbonate changes in acid-base disorders

Metabolic acidosis (acute or chronic)	Expected $PaCO_2$ = (1.5 × bicarbonate) + 8 ± 2 (Winters formula)
Metabolic alkalosis (acute or chronic)	~7 mm Hg ↑ in $PaCO_2$ per 10 mEq/L ↑ in bicarbonate
Respiratory acidosis (chronic only*)	~4 mEq/L ↑ in bicarbonate per 10 mm Hg ↑ in $PaCO_2$
Respiratory alkalosis (chronic only*)	~4 mEq/L ↓ in bicarbonate per 10 mm Hg ↓ in $PaCO_2$

*Compensation for respiratory disturbances is minimal in the acute setting. The full level of chronic compensation is achieved after ~72 hr. For simplicity, normal baseline $PaCO_2$ and bicarbonate should be considered 40 mm Hg and 24 mEq/L, respectively.

Add To New Card | Existing Card

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A 68-year-old woman is brought to the emergency department due to worsening fever, cough, and confusion. The patient has had a "cold and congestion" since last week, which initially improved, but she began feeling worse again 3 days ago. Her daughter reports that the patient has also been eating poorly. Other medical conditions include chronic obstructive pulmonary disease and chronic kidney disease. Temperature is 39.4 C (102.9 F), blood pressure is 74/46 mm Hg, pulse is 128/min, and respirations are 30/min. Oxygen saturation is 94% on 2 L/min. On physical examination, the patient is lethargic with dry mucous membranes and flat neck veins. Lung examination reveals dullness to percussion and crackles at the right base. Chest x-ray shows a right lower lobe consolidation. Intravenous access is established. Intravenous administration of which of the following is the most appropriate next step in management of this patient?

- A. 0.45% saline
- B. 3% saline
- C. 5% dextrose in 0.45% saline
- D. Albumin solution
- E. Lactated Ringer solution
- F. Sodium bicarbonate solution

Submit

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- A. 0.45% saline (16%)
- B. 3% saline (11%)
- C. 5% dextrose in 0.45% saline (31%)
- D. Albumin solution (3%)
- ✓ E. Lactated Ringer solution (34%)
- F. Sodium bicarbonate solution (3%)

Omitted
Correct answer
E

34%
Answered correctly

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Time Spent

05/15/2020
Last Updated

Explanation

Intravenous fluids

Intravenous fluids		
Tonicity	**Fluid type**	**Clinical use**
Isotonic	0.9% (normal) saline	Volume resuscitation (eg, hypovolemia, shock)
	Lactated Ringer solution	
	Albumin (5% or 25%)*	Volume replacement, treatment of SBP or HRS
Hypotonic	Dextrose 5% in water**	Free water deficit
	0.45% (half-normal) saline	
	Dextrose 5% in 0.45% (half-normal) saline**	Maintenance hydration
Hypertonic	3% (hypertonic) saline	Severe, symptomatic hyponatremia

HRS = hepatorenal syndrome; **SBP** = spontaneous bacterial peritonitis.

*Colloid solution; all other listed fluid types are crystalloid solutions.

**Dextrose 5% in water (initially slightly hypotonic) & dextrose 5% in 0.45% saline (initially hypertonic) become markedly hypotonic due to metabolism of glucose.

This patient with fever, cough, and radiologic evidence of consolidation in the right lower lung has **pneumonia**. Her tachycardia, **hypotension**, and confusion (evidence of **end-organ hypoperfusion**) are most likely due to **septic shock**, which is characterized by increased permeability of the vascular endothelium with leakage of intravascular fluid into the extravascular space.

In the management of septic shock, rapid restoration of intravascular volume and adequate end-organ perfusion is critical. This is best accomplished with the administration of boluses of **isotonic crystalloid** in the form of 0.9% (normal) saline or lactated Ringer solution through large-bore, peripheral intravenous catheters. These solutions are ideal for volume resuscitation because they have osmolarity very close to the normal osmolarity of the blood (~285 mOsm/kg H_2O), while the sodium and chloride ions help retain the fluid in the extracellular space.

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Prompt initiation of appropriate empiric antibiotic therapy is also critical in the management of septic shock.

(Choices A and C) 0.45% (half-normal) saline is hypotonic; 5% dextrose in 0.45% saline is hypertonic initially but becomes hypotonic following infusion because the dextrose is rapidly metabolized. These hypotonic solutions are often used at low infusion rates for patients with a deficiency of free water (ie, hypernatremia) or for maintenance hydration. However, they are not effective for rapid volume resuscitation because the low osmolarity causes much of the fluid volume to shift into the intracellular space following infusion.

(Choice B) Infusion of 3% (hypertonic) saline can lead to rapid fluid-shifting from the intracellular to the extracellular space with potentially devasting consequences (eg, osmotic demyelination syndrome); therefore, 3% saline is not appropriate for rapid volume resuscitation. It is appropriate for careful use in patients with severe symptomatic hyponatremia.

(Choice D) Albumin solution is an isotonic colloid solution that can be used for rapid volume resuscitation. However, it is less preferred due to high cost and limited availability compared to isotonic crystalloid.

(Choice F) Sodium bicarbonate solutions can have variable tonicity and are typically used at low infusion rates for patients with severe metabolic acidosis. These solutions are generally not used for rapid volume resuscitation.

Educational objective:

accomplished with the administration of boluses of **isotonic crystalloid** in the form of 0.9% (normal) saline or lactated Ringer solution through large-bore, peripheral intravenous catheters. These solutions are ideal for volume resuscitation because they have osmolarity very close to the normal osmolarity of the blood (~285 mOsm/kg H_2O), while the sodium and chloride ions help retain the fluid in the extracellular space.

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Educational objective:
The initial management of septic shock requires rapid fluid resuscitation to replace intravascular volume and restore adequate end-organ perfusion. This is best accomplished with intravenous boluses of isotonic crystalloid in the form of 0.9% (normal) saline or lactated Ringer solution because these solutions remain in the extracellular space.

Physiology	Pulmonary & Critical Care	Sepsis
Subject	System	Topic

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An 81-year-old man comes to the office after an upper respiratory tract infection. His symptoms have largely resolved except for a mild, nonproductive cough that is especially bothersome at night. Medical history includes hypertension and knee osteoarthritis. The patient is still physically active and plays golf on the weekends. He is a retired insurance executive and has no known environmental exposures. He has no history of smoking. Physical examination is unremarkable, and chest x-ray is normal. Pulmonary function testing is considered in this patient. Compared to midlife, which of the following changes are most likely expected as a result of normal aging in this patient?

	Total lung capacity	Forced vital capacity	Residual volume
A.	↑	↑	↑
B.	Unchanged	↑	↑
C.	Unchanged	↓	↑
D.	↓	↑	↓
E.	↓	↓	↓

Submit

An 81-year-old man comes to the office after an upper respiratory tract infection. His symptoms have largely resolved except for a mild, nonproductive cough that is especially bothersome at night. Medical history includes hypertension and knee osteoarthritis. The patient is still physically active and plays golf on the weekends. He is a retired insurance executive and has no known environmental exposures. He has no history of smoking. Physical examination is unremarkable, and chest x-ray is normal. Pulmonary function testing is considered in this patient. Compared to midlife, which of the following changes are most likely expected as a result of normal aging in this patient?

	Total lung capacity	Forced vital capacity	Residual volume
A. (10%)	↑	↑	↑
B. (3%)	Unchanged	↑	↑
✓ C. (57%)	Unchanged	↓	↑
D. (5%)	↓	↑	↓
E. (23%)	↓	↓	↓

Omitted
Correct answer
C

57%
Answered correctly

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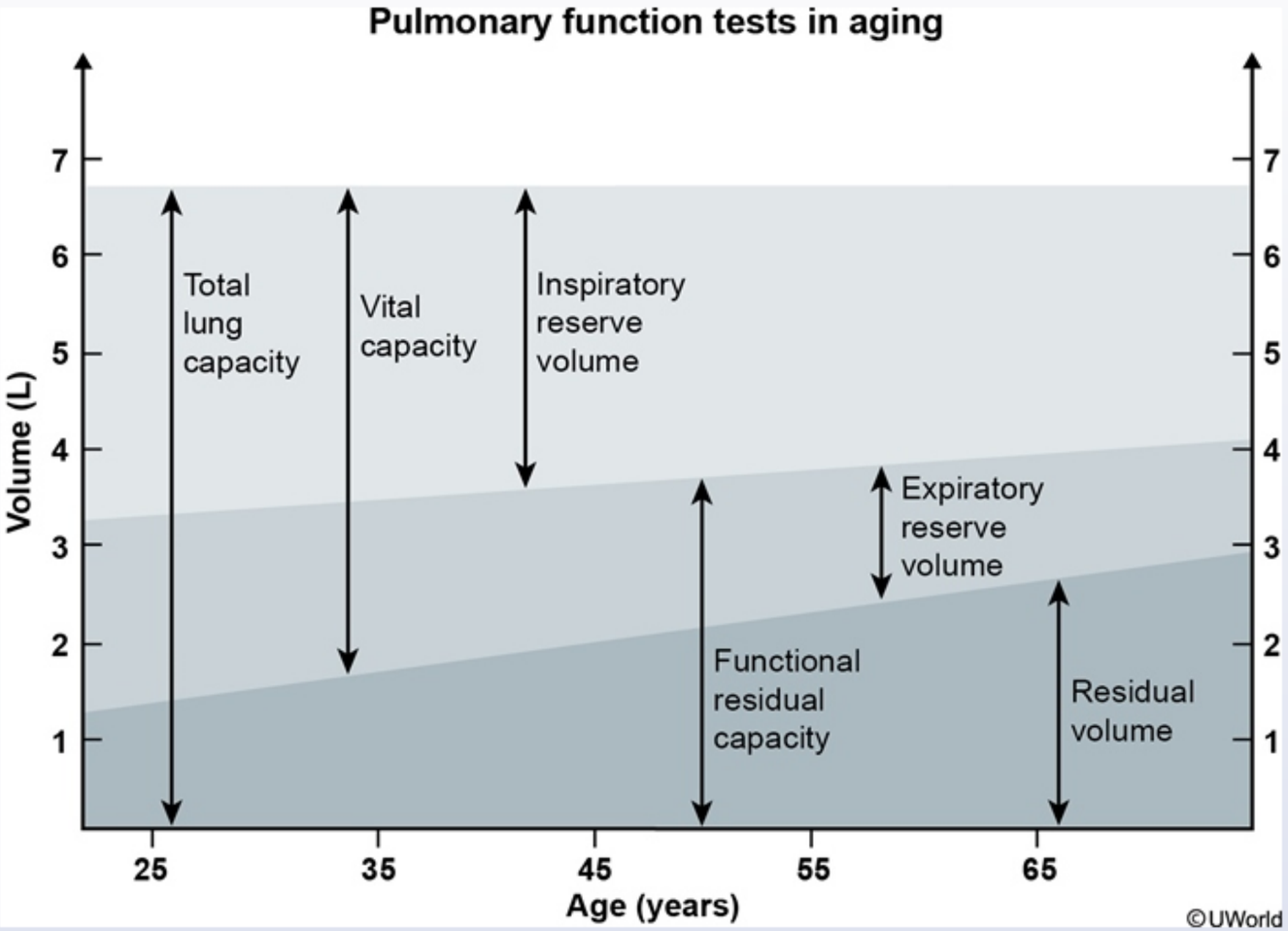
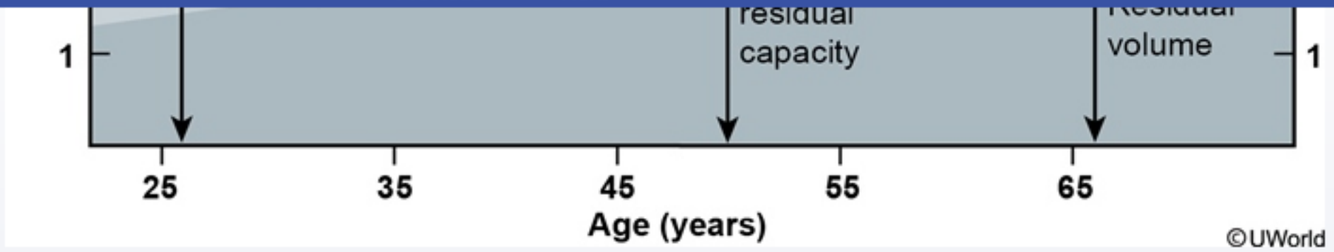
Time Spent

06/17/2020
Last Updated

Explanation



Aging is associated with a number of changes in pulmonary function. Patients age >35 experience steady decreases in chest wall compliance as a result of stiffening from rib calcification and from increased thoracic curvature due to osteoporosis and osteoarthritis. In contrast, lung compliance increases with age due to a loss of elastic recoil, particularly in the alveolar ducts. The dilation of alveolar ducts is homogenous, as opposed to the emphysema associated with chronic obstructive pulmonary disease, and is not associated with destruction of the alveolar walls.



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Diminished elastic recoil and the collapse of supporting tissues around the airways cause a significant **increase** in **residual volume** (RV). However, **total lung capacity** (TLC) remains **unchanged** because the decreased chest wall compliance counterbalances increases in lung compliance **(Choices A, D, and E)**. In addition, as RV becomes a much higher proportion of TLC (due to air trapping), forced vital capacity also decreases **(Choice B)**. Other age-associated changes include decreases in forced expiratory volume in 1 second and diffusing capacity.

Educational objective:
Aging is associated with steady decreases in chest wall compliance but increases in lung compliance due to a loss of elastic recoil. This results in a marked increase in residual volume, a decrease in forced vital capacity, and relatively unchanged total lung capacity.

References

- Effect of aging on respiratory system physiology and immunology.
- Physiological changes in respiratory function associated with ageing.

Physiology	Pulmonary & Critical Care	Aging
Subject	System	Topic

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A 28-year-old professional athlete participates in a sports physiology study. She runs on a treadmill at an incrementally increasing speed. After 15-minutes, her pulse is 90% of the maximal heart rate based on her age, and several physiologic parameters are measured. Which of the following changes have most likely occurred compared to at rest?

	Minute ventilation	Ventilation/perfusion ratio	Mixed venous oxygen content
A.	Decreased	Increased	Unchanged
B.	Increased	Decreased	Decreased
C.	Increased	Increased	Decreased
D.	Increased	Unchanged	Increased
E.	Unchanged	Unchanged	Increased

Submit

A 28-year-old professional athlete participates in a sports physiology study. She runs on a treadmill at an incrementally increasing speed. After 15-minutes, her pulse is 90% of the maximal heart rate based on her age, and several physiologic parameters are measured. Which of the following changes have most likely occurred compared to at rest?

	Minute ventilation	Ventilation/perfusion ratio	Mixed venous oxygen content
A. (1%)	Decreased	Increased	Unchanged
B. (19%)	Increased	Decreased	Decreased
✓ C. (56%)	Increased	Increased	Decreased
D. (20%)	Increased	Unchanged	Increased
E. (1%)	Unchanged	Unchanged	Increased

Omitted
Correct answer
C

56%
Answered correctly

02 secs
Time Spent

06/30/2020
Last Updated

Explanation

Explanation

During **exercise**, respiratory activity changes to help meet the body's **increased metabolic demand**:

- **Increased minute ventilation** occurs via an increase in respiratory rate and tidal volume and facilitates an increased rate of **oxygen uptake** and **carbon dioxide removal**. The increase in tidal volume can reach up to 50% of resting vital capacity.
- The increased minute ventilation **increases alveolar ventilation** throughout the lungs. Pulmonary vascular resistance is reduced and cardiac output is increased, which allows for more evenly distributed blood flow throughout the lungs and **reduced physiologic dead space** (ie, reduction in the proportion of air in the respiratory tract that does not participate in gas exchange). Although blood flow through the lungs is increased, alveolar ventilation needs to increase more (blood flowing through the lungs during exercise is more deoxygenated than normal), resulting in an **increased ventilation-perfusion ratio**.

In addition, an accumulation of lactic acid decreases blood pH and stimulates a **rightward shift** in the hemoglobin dissociation curve, facilitating **increased unloading of oxygen** in skeletal muscle. Although increased cardiac output increases the rate of blood flow through the skeletal muscle capillaries and reduces the time allowed for oxygen unloading, the fraction of arterial oxygen extracted by skeletal muscle markedly increases during exercise, resulting in **decreased mixed venous oxygen content**.

These physiologic changes in the respiratory system that occur during exercise are most pronounced in highly trained athletes.

Educational objective:
Physiologic changes in the respiratory system that occur with exercise include increased minute ventilation (via both an increase in respiratory rate and tidal volume), reduced physiologic dead space, increased ventilation-perfusion ratio, and increased extraction of oxygen by skeletal muscle (resulting in decreased mixed venous oxygen content).

Physiology	Pulmonary & Critical Care	Physical exercise
Subject	System	Topic

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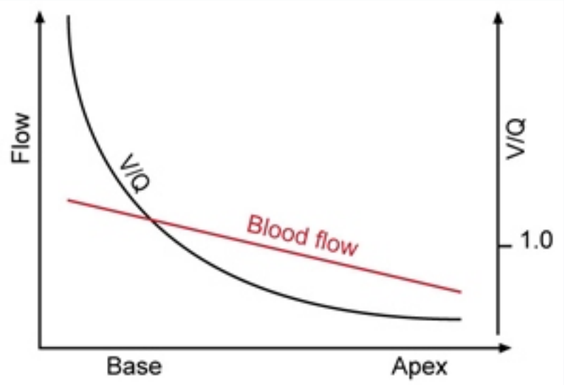
Researchers are measuring regional variations in pulmonary ventilation (V) and blood flow (Q) in healthy individuals while they stand in the upright position. The results are graphed with the x-axis denoting the position along the lung from base to apex. Which of the following curves is most likely to be observed?

A.



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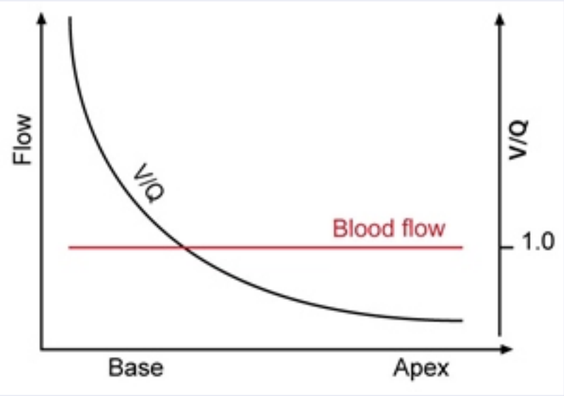

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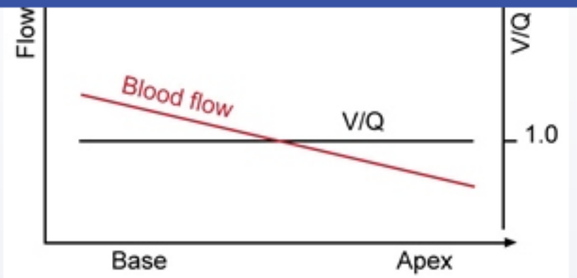

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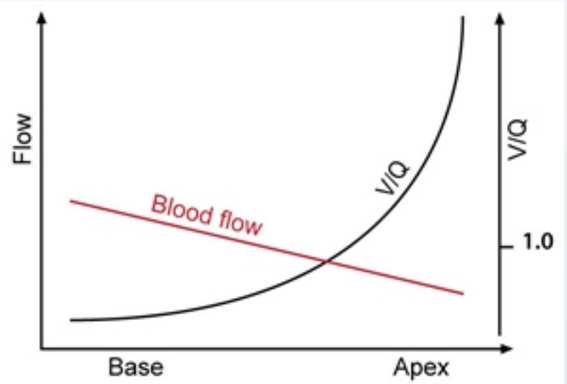

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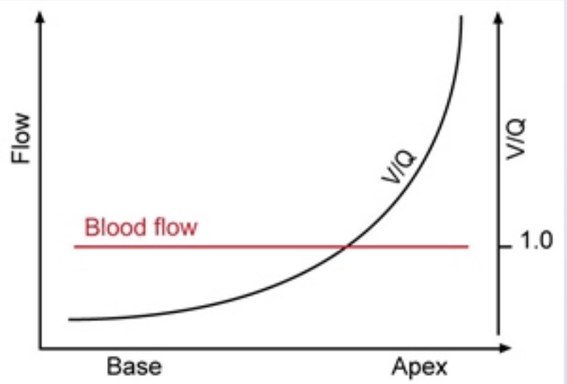

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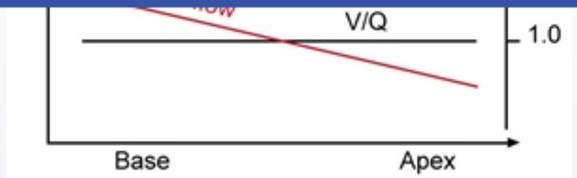
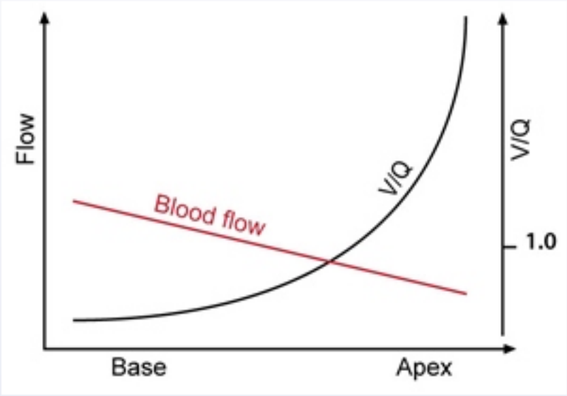
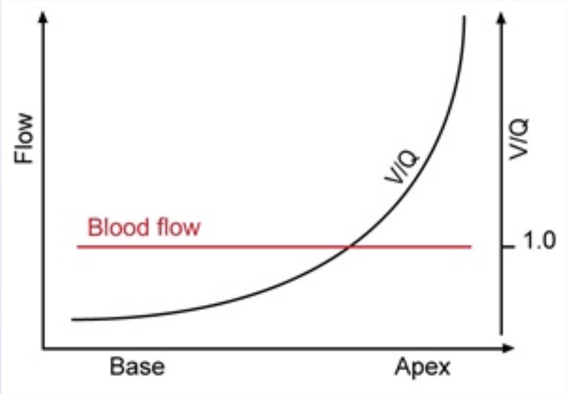


D. (75%)



E. (3%)



Omitted
Correct answer

75%
Answered correctly

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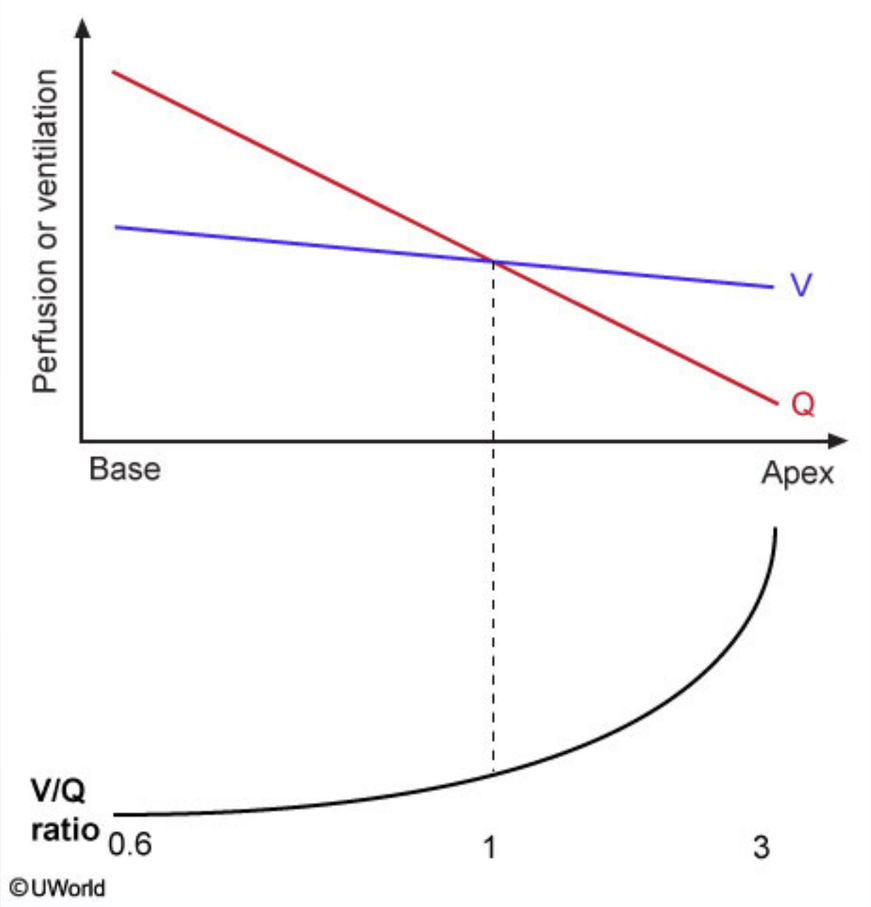

In the upright position, regional differences in ventilation and perfusion occur vertically in the lungs due to gravity. **Ventilation** is **lowest in the apex** and **highest in the base** because gravity acts to stretch the lungs downward so that the alveoli at the apex are expanded more than those at the base. Therefore, during inspiration a small amount of air goes to the apex where alveoli are distended and less compliant, while more air goes to the base where alveoli have ample potential space to fill and are more compliant. **Perfusion** is also **lowest in the apex** and **highest in the base**, as the increased hydrostatic pressure in the lower lung regions facilitates increased blood flow.

In the upright position, regional differences in ventilation and perfusion occur vertically in the lungs due to gravity. **Ventilation** is **lowest in the apex** and **highest in the base** because gravity acts to stretch the lungs downward so that the alveoli at the apex are expanded more than those at the base. Therefore, during inspiration a small amount of air goes to the apex where alveoli are distended and less compliant, while more air goes to the base where alveoli have ample potential space to fill and are more compliant. **Perfusion** is also **lowest in the apex** and **highest in the base**, as the increased hydrostatic pressure in the lower lung regions facilitates increased blood flow.

Because blood is denser than air or lung tissue, the gravitational effect on perfusion is more pronounced than on ventilation, leading to **greater variability in perfusion than ventilation** from apex to base. Therefore, perfusion is very low in the apex and very high in the base, whereas ventilation is only somewhat low in the apex and somewhat high in the base. This causes the gradient of the ventilation/perfusion (V/Q) ratio to be opposite of the gradient of perfusion or ventilation taken individually. The **V/Q ratio** is **lowest at the base** and **highest at the apex**.

(Choices A and B) These graphs depict the V/Q ratio decreasing from base to apex, which is the opposite of what occurs.

(Choice C) This graph depicts a constant V/Q ratio of 1.0 throughout the lung, which does not occur. The V/Q ratio varies from approximately 0.6 at the base to 3.0 at the apex. A value of 0.8 is often considered the average V/Q ratio for normal lungs.

(Choice E) This graph shows constant perfusion throughout the lung, which does not occur.

Educational objective:
Both perfusion and ventilation are highest in the base of the lung and lowest in the apex; however, the variability in perfusion is greater than that in ventilation. This causes the ventilation/perfusion ratio to follow the opposite gradient: it is lowest in the base and highest in the apex.

Physiology	Pulmonary & Critical Care	Respiratory physiology
Subject	System	Topic

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A 52-year-old man is brought to the emergency department after being found unresponsive on the street. The patient's medical history is unknown. Temperature is 36.2 C (97.2 F), blood pressure is 108/62 mm Hg, and pulse is 72/min. On physical examination, he is unresponsive to verbal and tactile stimuli but moans to deep sternal rub. An arterial blood gas analysis on room air shows a partial pressure of oxygen of 60 mm Hg. The partial pressure of oxygen in his alveoli is calculated to be 68 mm Hg. Which of the following is the most likely cause of this patient's symptoms?

A. Alveolar hypoventilation
B. Dead space ventilation
C. Diffusion impairment
D. Intrapulmonary shunt
E. Left-to-right shunt

Submit

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- ✓ A. Alveolar hypoventilation (58%)
- B. Dead space ventilation (9%)
- C. Diffusion impairment (20%)
- D. Intrapulmonary shunt (8%)
- E. Left-to-right shunt (2%)

Omitted
Correct answer
A

58%
Answered correctly

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Explanation

Alveolar hypoventilation

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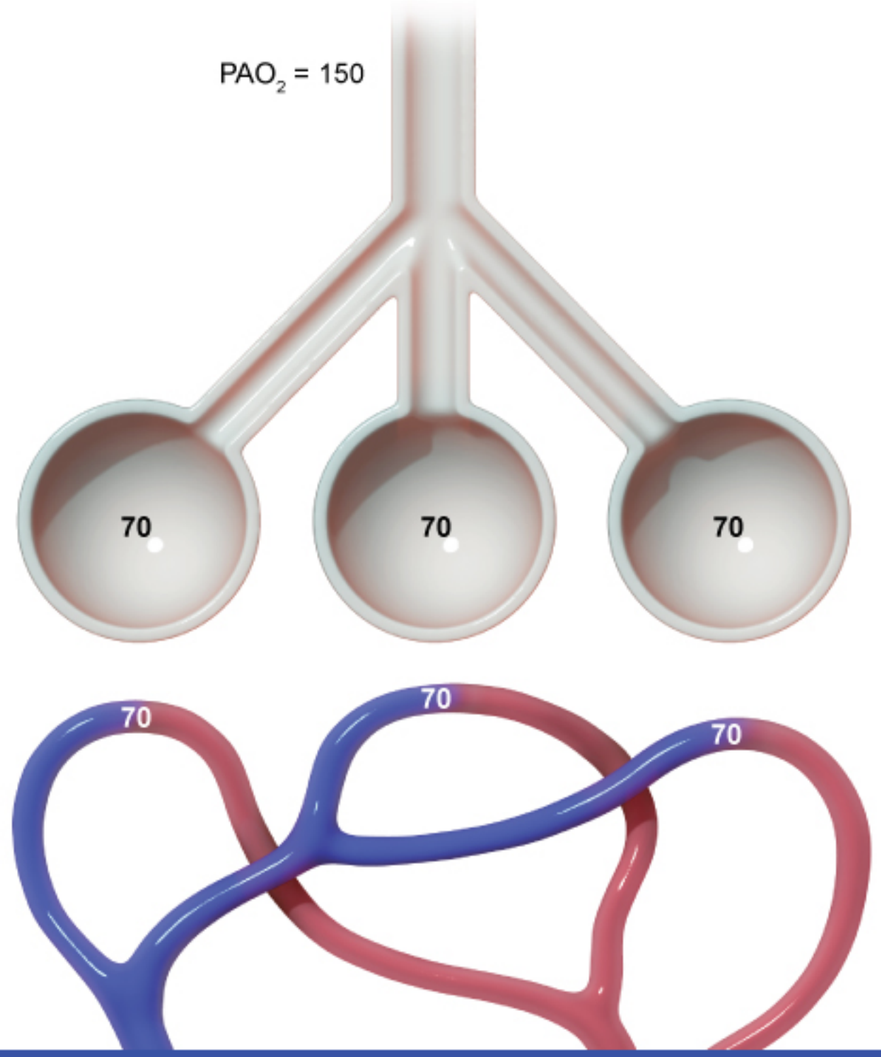
Alveolar hypoventilation



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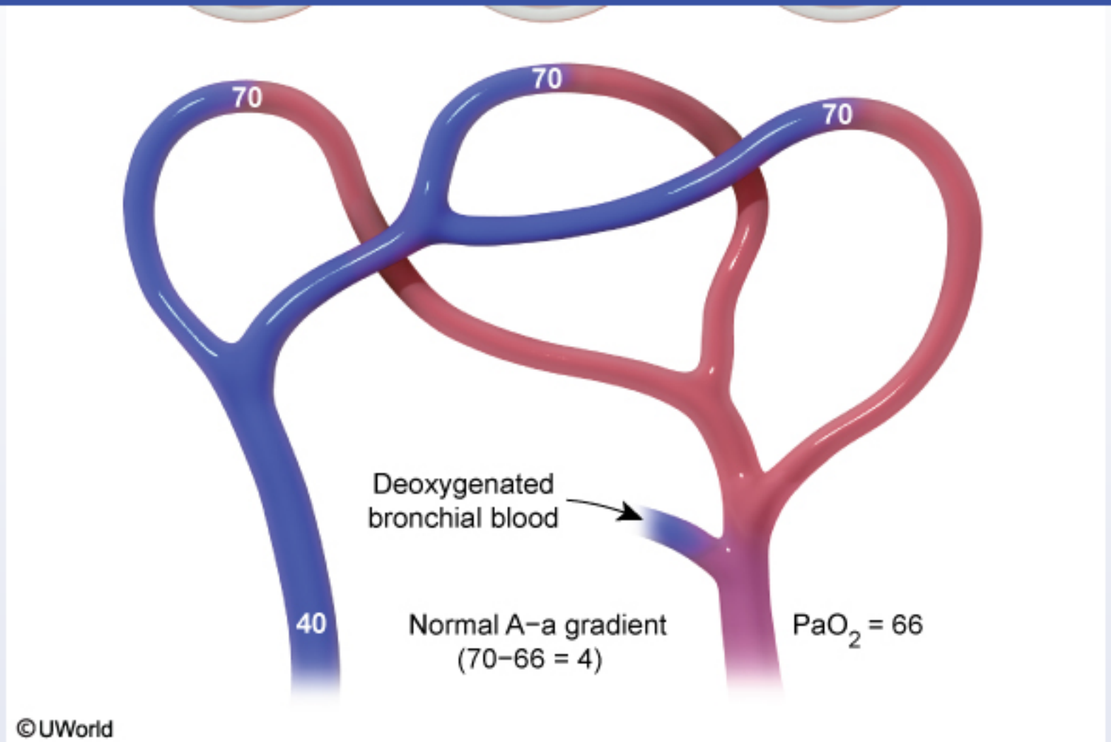

The partial pressure of oxygen in the alveoli (PAO_2) is normally 104 mm Hg, and due to the high rate of O_2 diffusion across the alveolar-capillary membrane, the O_2 level in the alveolar capillary blood rapidly equilibrates with the PAO_2. However, the blood O_2 level then drops slightly due to the addition of deoxygenated blood from the bronchial circulation; therefore, the partial pressure of oxygen in arterial blood (PaO_2) is normally around 100 mm Hg. This discrepancy between alveolar and arterial O_2 concentration is termed the alveolar-arterial (A-a) gradient. In healthy individuals, a **normal A-a gradient** is typically between **4 and 15 mm Hg**, with older individuals having higher normal values due to an age-related decline in O_2-diffusing capacity.

This patient has low PaO_2 and PAO_2 with a normal A-a gradient (68 − 60 = 8), indicating that his low PaO_2 is directly due to low PAO_2. Possible causes of hypoxemia in the setting of a normal A-a gradient include **alveolar hypoventilation** and low partial pressure of inspired oxygen (PiO_2) (ie, high altitude). Common causes of alveolar hypoventilation include suppressed central respiratory drive (eg, sedative overdose) and diseases

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(Choices B and D) Dead space ventilation is one extreme of ventilation-perfusion mismatch that occurs when the alveoli are adequately ventilated, but there is no alveolar perfusion (eg, pulmonary embolism). An intrapulmonary shunt is the other extreme of ventilation-perfusion mismatch that occurs when blood perfuses alveoli that are not ventilated (eg, pneumonia, pulmonary edema). The A-a gradient is elevated in ventilation-perfusion mismatch.

(Choice C) Gas diffusion is impaired in diseases that disrupt the alveolar-capillary membrane, such as alveolar hyaline membrane disease (acutely) or emphysema (chronically). Diffusion impairment causes an elevated A-a gradient because O_2 cannot be effectively transported into the blood.

(Choice E) A left-to-right shunt occurs when oxygenated blood from the left side of the heart is shunted into the right side of the heart (eg, atrial or ventricular septal defect). Left-to-right shunts do not cause hypoxemia; however, if left untreated, they may progress into a right-to-left shunt (ie, Eisenmenger syndrome) with hypoxemia, cyanosis, and an elevated A-a gradient.

Educational objective:
There are 5 major causes of hypoxemia (low arterial partial pressure of oxygen [PaO_2]): alveolar hypoventilation, low partial pressure of inspired oxygen, ventilation-perfusion mismatch, diffusion impairment, and right-to-left shunting. The A-a gradient is normal with alveolar hypoventilation

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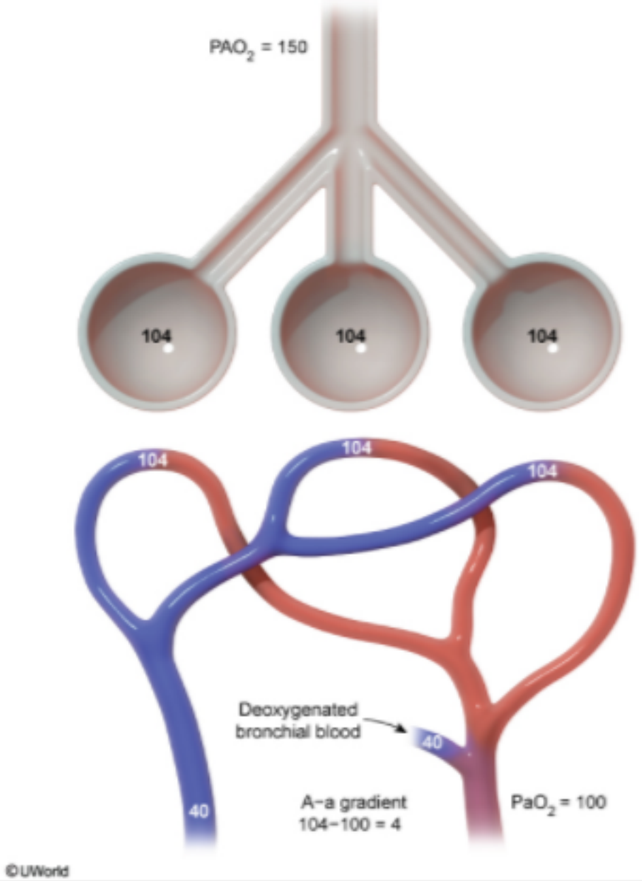
Exhibit Display

Normal bronchopulmonary shunting



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oxygen; ventilation-perfusion mismatch; diffusion impairment; and right-to-left shunting. The A-a gradient is normal with alveolar hypoventilation

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(Choices B and D) Dea
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(Choice C) Gas diffusio
(acutely) or emphysema to the
blood.

(Choice E) A left-to-righ rial or
ventricular septal defect) (ie,
Eisenmenger syndrome)

Educational objective:
There are 5 major cause ed
oxygen, ventilation-perfusion mismatch, diffusion impairment, and right-to-left shunting. The A-a gradient is normal with alveolar hypoventilation

Exhibit Display

Causes of hypoxemia

	Examples	A-a gradient
Reduced PiO_2	High altitude	Normal
Hypoventilation	CNS depression, morbid obesity	Normal
Diffusion limitation	Emphysema, ILD	Increased
V/Q mismatch*	Pulmonary embolism, pneumonia	Increased

*Caused by regional dead-space ventilation and/or intrapulmonary shunting.
A-a gradient = alveolar to arterial oxygen gradient; **ILD** = interstitial lung disease; **PiO_2** = partial pressure of inspired oxygen; **V/Q** = ventilation/perfusion ratio.

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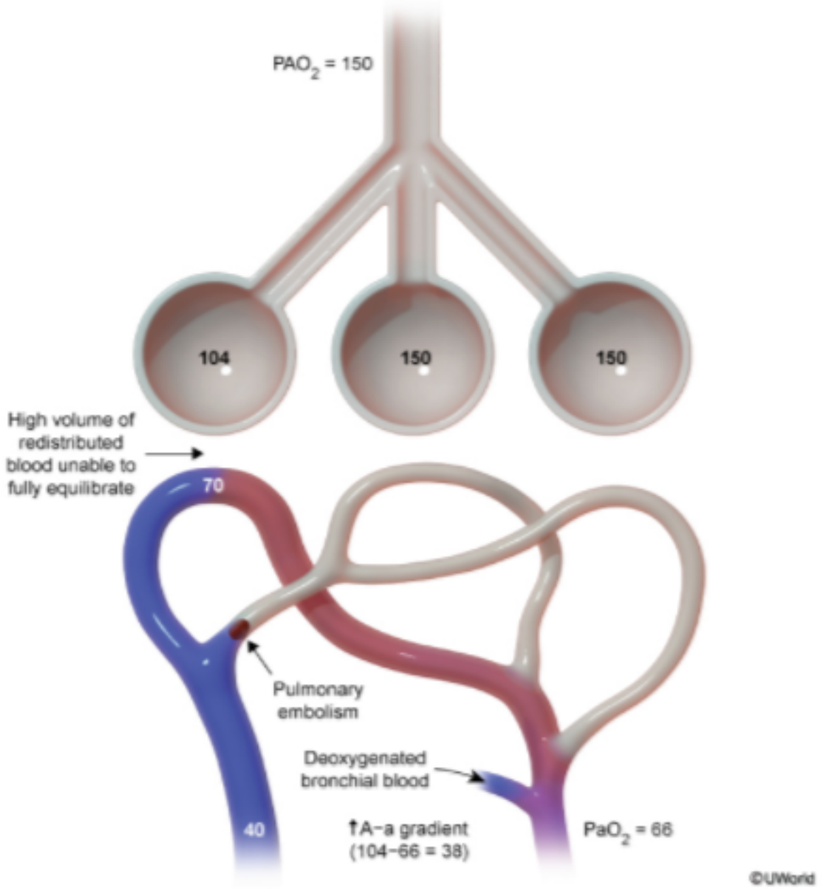
Exhibit Display

Dead space ventilation with V/Q mismatch



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oxygen; ventilation-perfusion mismatch; diffusion impairment; and right-to-left shunting. The A-a gradient is normal with alveolar hypoventilation

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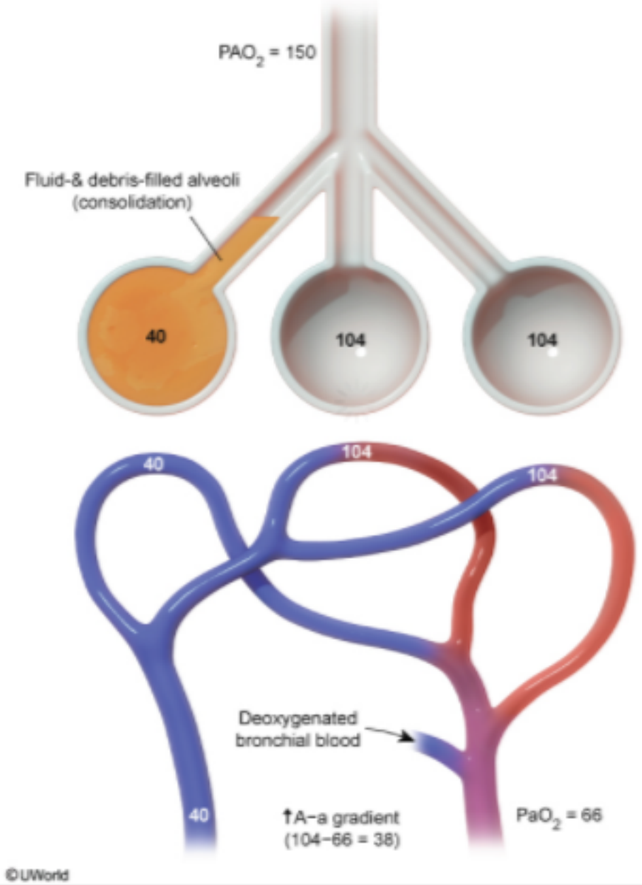
Exhibit Display

Intrapulmonary shunting with V/Q mismatch



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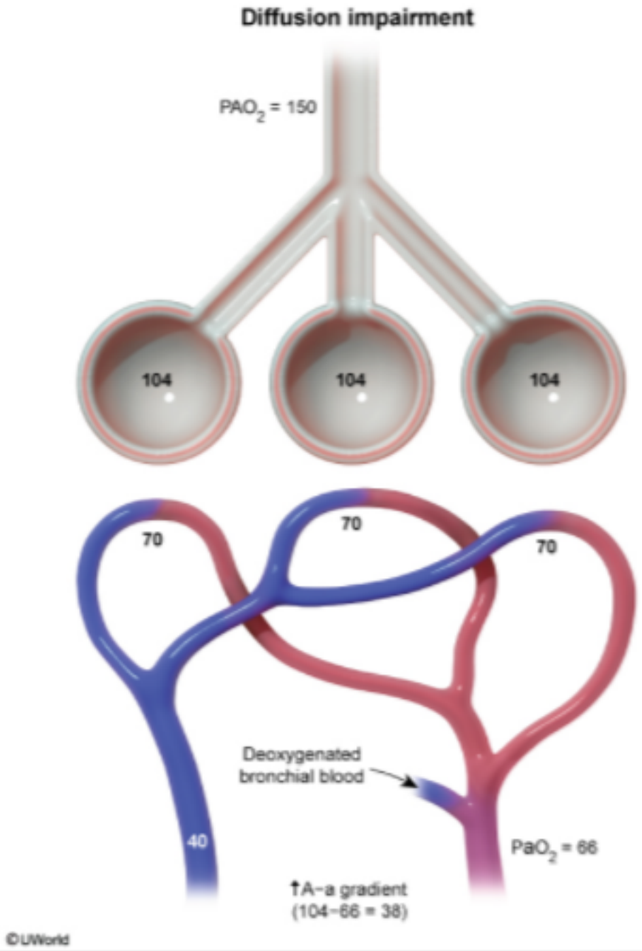

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Educational objective:
There are 5 major causes of hypoxemia (low arterial partial pressure of oxygen [PaO_2]): alveolar hypoventilation, low partial pressure of inspired oxygen, ventilation-perfusion mismatch, diffusion impairment, and right-to-left shunting. The A-a gradient is normal with alveolar hypoventilation and low partial pressure of inspired oxygen, which helps distinguish these causes from other causes of hypoxemia.

Physiology	Pulmonary & Critical Care	Acute respiratory failure
Subject	System	Topic

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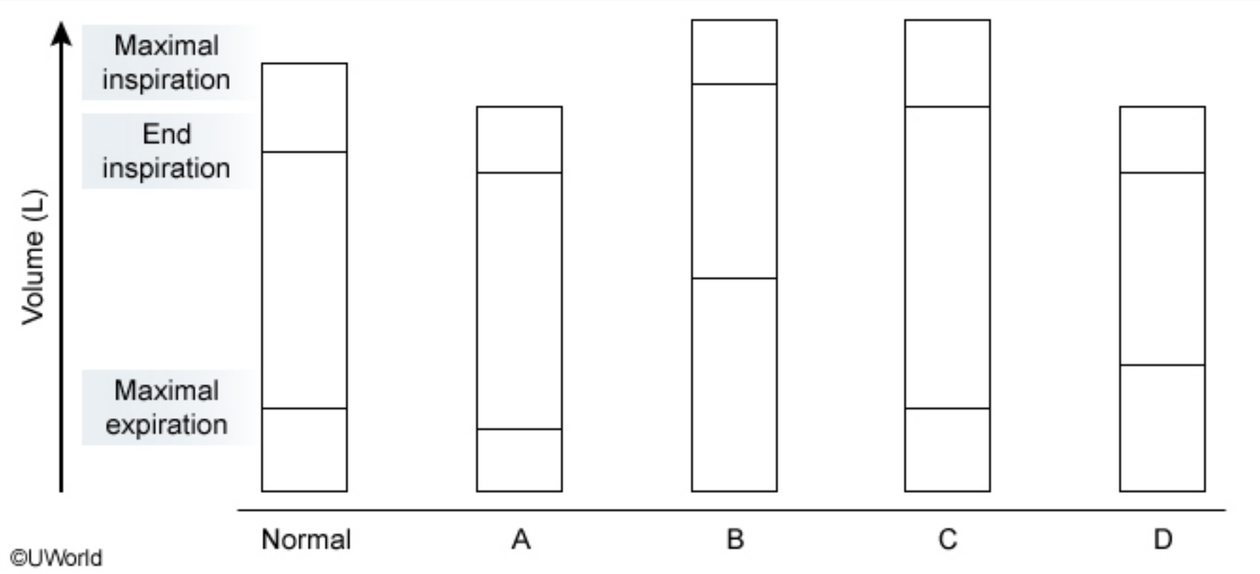
A 64-year-old man is evaluated for worsening dyspnea on exertion. He has a 40-pack-year smoking history. The lungs are hyperresonant on percussion and there is diffuse wheezing on auscultation. Chest x-ray reveals a flattened diaphragm with a narrow mediastinum, and there are decreased bronchovascular markings in the peripheral lung region. Which of the following lung volume patterns is most likely to be present in this patient? (Each bar represents total lung capacity with different volumes as marked.)



A. A
B. B
C. C
D. D

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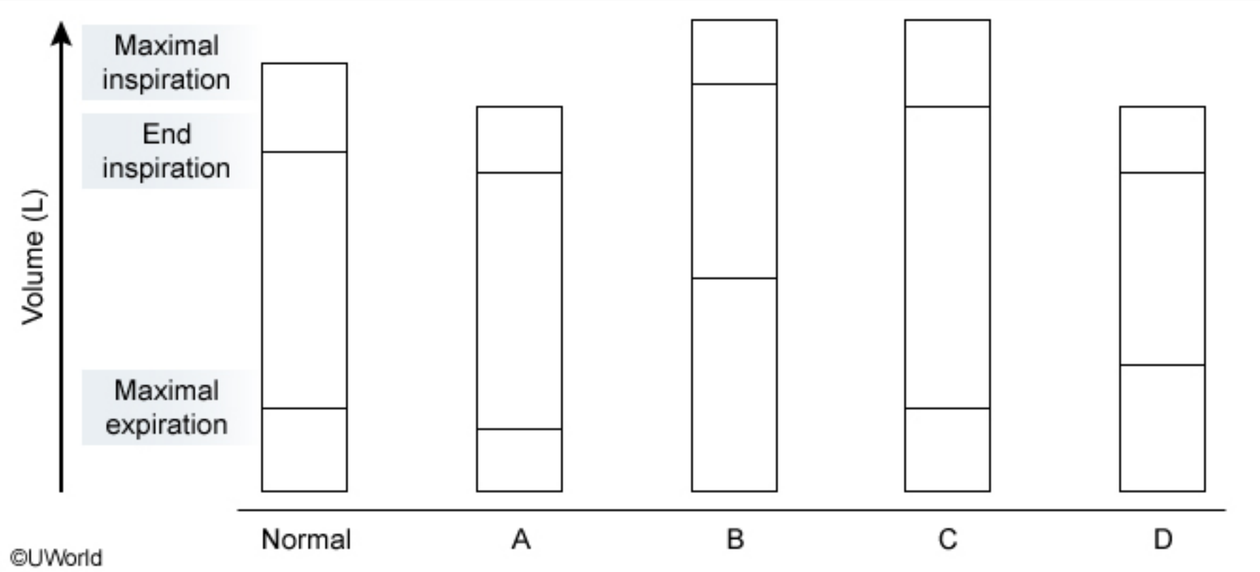

A. A (7%)
✓ B. B (70%)
C. C (17%)
D. D (4%)

Omitted
Correct answer

70%
Answered correctly

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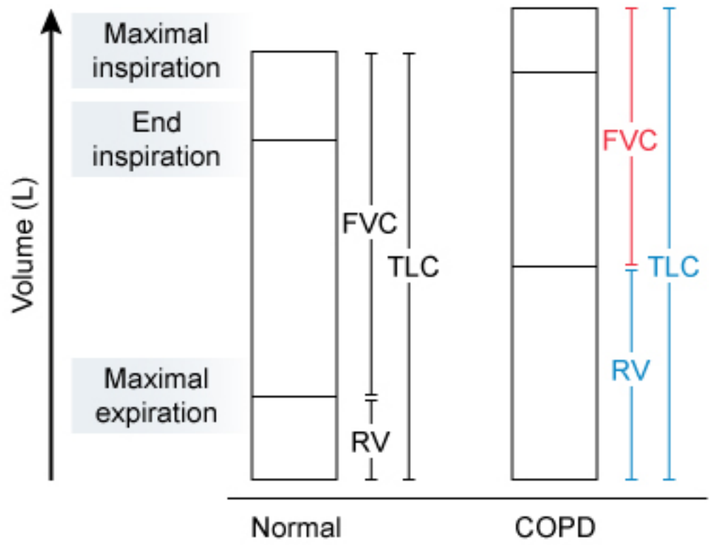
Last Updated



FVC = forced vital capacity; **RV** = residual volume; **TLC** = total lung capacity.
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In **chronic obstructive pulmonary disease** (COPD), air flow obstruction and hyperinflation (air trapping) cause **increased residual volume** (RV) and a consequent **increase in total lung capacity** (TLC). Because the increase in RV is greater than the increase in TLC, the RV/TLC ratio is increased. Airway obstruction also causes **decreased forced vital capacity** (FVC) and a more profound decrease in forced expiratory volume in one second (FEV1), resulting in a decreased FEV1/FVC ratio.

In the above graphs, the top section represents the inspiratory reserve volume, the middle section represents the tidal volume plus the expiratory reserve volume, and the bottom section represents the RV. In COPD, an increase in RV and TLC is expected, as is a decrease in FVC.

(Choice A) In restrictive lung disease, the TLC, RV, FVC, and FEV1 are all reduced, but the FEV1/FVC ratio is normal or increased.

(Choice C) This graph shows an increased TLC and FVC with a normal RV. Such an increase in FVC may be seen in elite athletes.

(Choice D) This graph shows a decrease in TLC and an increase in RV. As changes in these parameters are not typically discordant, this would be a rare clinical finding.

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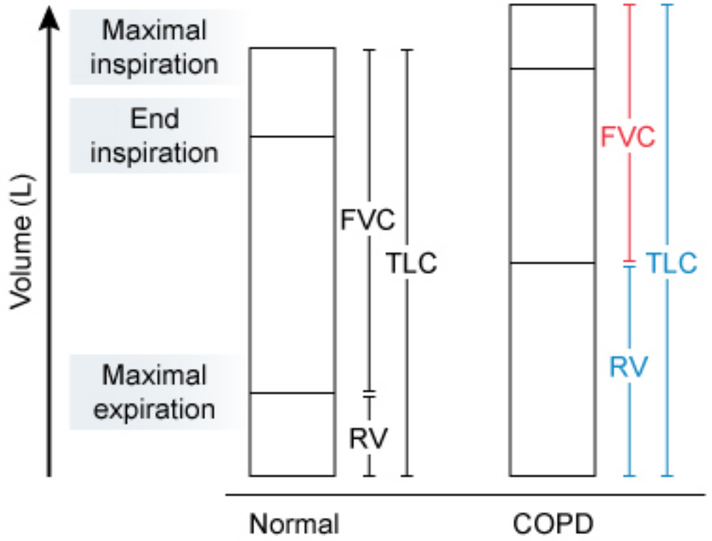
Explanation



FVC = forced vital capacity; **RV** = residual volume; **TLC** = total lung capacity.
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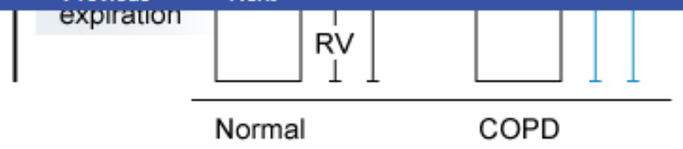
In **chronic obstructive pulmonary disease** (COPD), air flow obstruction and hyperinflation (air trapping) cause **increased residual volume** (RV) and a consequent **increase in total lung capacity** (TLC). Because the increase in RV is greater than the increase in TLC, the RV/TLC ratio is increased. Airway obstruction also causes **decreased forced vital capacity** (FVC) and a more profound decrease in forced expiratory volume in one second (FEV1), resulting in a decreased FEV1/FVC ratio.

In the above graphs, the top section represents the inspiratory reserve volume, the middle section represents the tidal volume plus the expiratory reserve volume, and the bottom section represents the RV. In COPD, an increase in RV and TLC is expected, as is a decrease in FVC.

(Choice A) In restrictive lung disease, the TLC, RV, FVC, and FEV1 are all reduced, but the FEV1/FVC ratio is normal or increased.

(Choice C) This graph shows an increased TLC and FVC with a normal RV. Such an increase in FVC may be seen in elite athletes.



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(Choice A) In restrictive lung disease, the TLC, RV, FVC, and FEV1 are all reduced, but the FEV1/FVC ratio is normal or increased.

(Choice C) This graph shows an increased TLC and FVC with a normal RV. Such an increase in FVC may be seen in elite athletes.

(Choice D) This graph shows a decrease in TLC and an increase in RV. As changes in these parameters are not typically discordant, this would be a rare clinical finding.

Educational objective:
In chronic obstructive pulmonary disease, air-trapping leads to an increase in residual volume (RV) and total lung capacity (TLC), as well as an increase in the RV/TLC ratio. Airway obstruction causes a decrease in forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), and the FEV1/FVC ratio.

Physiology	Pulmonary & Critical Care	COPD
Subject	System	Topic

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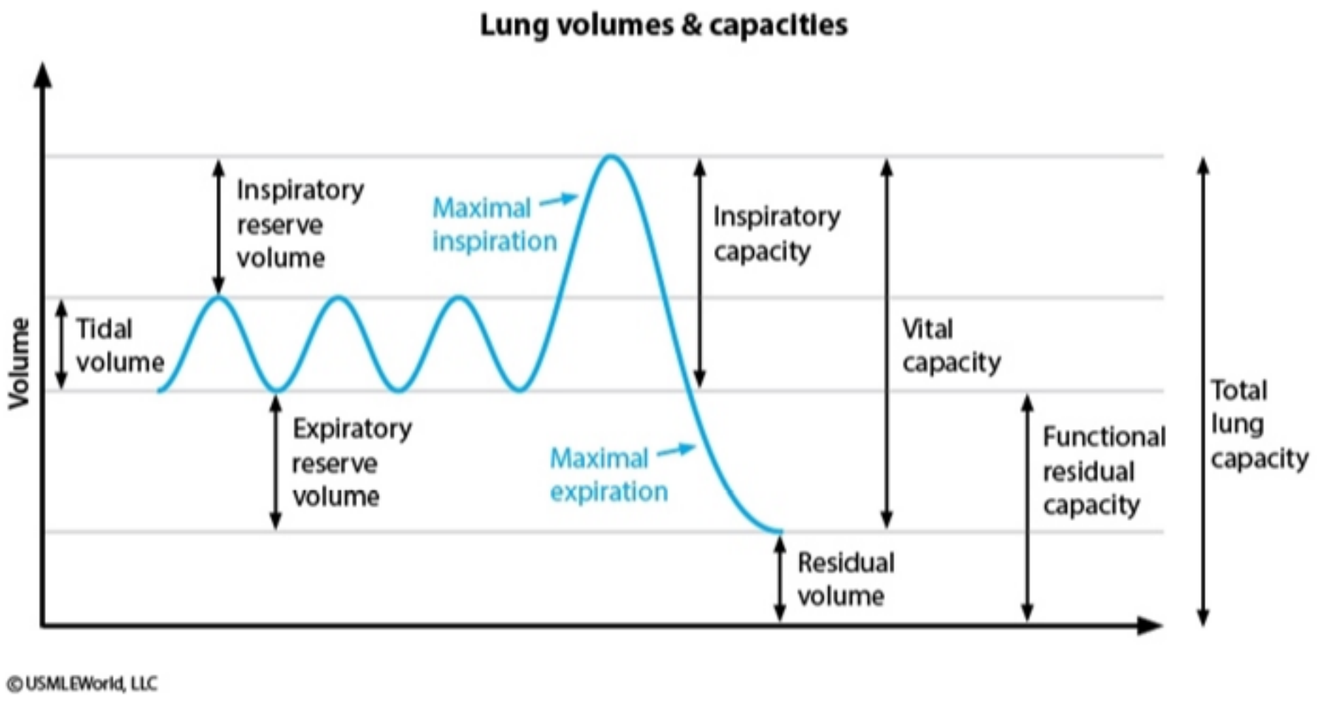

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A 23-year-old man undergoes exercise physiology testing at sea level. He jogs on a treadmill to achieve a moderate-intensity physical activity level based on a target heart rate of 50%-70% of his estimated maximum heart rate. An increase in which of the following is expected at the peak of his exertion?

A. Arterial blood mean CO_2 content

B. Arterial blood mean O_2 content

C. Hemoglobin affinity for O_2

D. pH of the arterial blood

E. Physiologic dead space

F. Venous blood mean CO_2 content

G. Venous blood mean O_2 content

Submit

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A. Arterial blood mean CO_2 content (5%)

B. Arterial blood mean O_2 content (7%)

C. Hemoglobin affinity for O_2 (3%)

D. pH of the arterial blood (3%)

E. Physiologic dead space (1%)

✓ F. Venous blood mean CO_2 content (75%)

G. Venous blood mean O_2 content (2%)

Omitted
Correct answer
F

75%
Answered correctly

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Time Spent

02/09/2020
Last Updated

Explanation

Long-distance running and other forms of physical exercise cause **increased oxidative metabolism** of glucose and fatty acids in the skeletal muscle. This markedly increases the rates of O_2 consumption and CO_2 production, which must be balanced by increases in skeletal muscle perfusion and alveolar ventilation.

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Long-distance running and other forms of physical exercise cause **increased oxidative metabolism** of glucose and fatty acids in the skeletal muscle. This markedly increases the rates of O_2 consumption and CO_2 production, which must be balanced by increases in skeletal muscle perfusion and alveolar ventilation.

The cardiovascular response to exercise involves vasoconstriction in the splanchnic circulation and **vasodilation in skeletal muscle**, shunting blood toward exercising muscle. The vasodilation is predominant, resulting in overall **decreased systemic vascular resistance**. There is also an increase in heart rate and stroke volume that markedly **increases cardiac output** and O_2 delivery to the tissues. Increased O_2 extraction by the tissues leads to a concomitant **increase in CO_2 production**, which is absorbed by the systemic capillaries and transported in high quantities via venous blood to the lungs, where it is expired.

(Choices A and B) Mean values for arterial O_2 and CO_2 content remain essentially constant during exercise, even during periods of intense exertion. This is likely accomplished via tight regulation of increases in alveolar ventilation and gas exchange efficiency.

(Choices C and D) Tissue pH typically decreases during exercise due to production of carbonic and lactic acid in active skeletal muscle. The acidic pH causes a decrease in hemoglobin affinity for O_2 (ie, right shift in the O_2-hemoglobin dissociation curve) to facilitate unloading of O_2 in the tissues. Although venous pH may decrease significantly during moderate exercise, there is typically little change in arterial pH due to respiratory compensation.

(Choice E) Physiologic dead space (ie, the air in the respiratory system that does not participate in gas exchange) is decreased during exercise due to a decrease in pulmonary vascular resistance that allows perfusion of additional pulmonary capillary beds.

(Choice G) The mean O_2 content of venous blood remains the same or decreases with exercise because the rate of O_2 extraction by the tissues outpaces the rate of oxygen delivery (cardiac output). In most healthy individuals, cardiac output is the major limiting factor to O_2 consumption during exercise.

Educational objective:
During physical exercise, there is increased skeletal muscle CO_2 production that increases the CO_2 content of venous blood. Arterial O_2 and CO_2 content remains constant via increases in alveolar ventilation and gas exchange efficiency. Venous O_2 content remains constant or is decreased due to increased O_2 extraction by the tissues that matches or exceeds the rate of oxygen delivery (ie, O_2 consumption during exercise is limited by cardiac output).

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blood toward exercising muscle. The vasodilation is predominant, resulting in overall **decreased systemic vascular resistance**. There is also an increase in heart rate and stroke volume that markedly **increases cardiac output** and O_2 delivery to the tissues. Increased O_2 extraction by the tissues leads to a concomitant **increase in CO_2 production**, which is absorbed by the systemic capillaries and transported in high quantities via venous blood to the lungs, where it is expired.

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Physiology	Pulmonary & Critical Care	Respiratory physiology
Subject	System	Topic

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A 54-year-old man comes to the office due to shortness of breath that has slowly worsened over the last 6 months. He also has a persistent, nonproductive cough. The patient does not use alcohol, tobacco, or illicit drugs. Temperature is 36.8 C (98 F), blood pressure is 132/78 mm Hg, pulse is 74/min, and respirations are 16/min. Physical examination reveals fine crackles bilaterally on pulmonary auscultation and drumstick-shaped fingers. Chest x-ray reveals diffuse reticular opacities. Pulmonary function testing shows decreased FVC, increased FEV1/FVC ratio, and expiratory flow rates that are higher than normal when corrected for lung volume. This patient's supernormal expiratory flow rates are best explained by an increase in which of the following parameters?

A. Lung compliance

B. Outward recoil of the chest wall

C. Physiological dead space

D. Radial traction on airway walls

E. Wall thickness of bronchioles

Submit

A 54-year-old man comes to the office due to shortness of breath that has slowly worsened over the last 6 months. He also has a persistent, nonproductive cough. The patient does not use alcohol, tobacco, or illicit drugs. Temperature is 36.8 C (98 F), blood pressure is 132/78 mm Hg, pulse is 74/min, and respirations are 16/min. Physical examination reveals fine crackles bilaterally on pulmonary auscultation and drumstick-shaped fingers. Chest x-ray reveals diffuse reticular opacities. Pulmonary function testing shows decreased FVC, increased FEV1/FVC ratio, and expiratory flow rates that are higher than normal when corrected for lung volume. This patient's supernormal expiratory flow rates are best explained by an increase in which of the following parameters?

- A. Lung compliance (14%)
- B. Outward recoil of the chest wall (10%)
- C. Physiological dead space (7%)
- ✓ D. Radial traction on airway walls (51%)
- E. Wall thickness of bronchioles (15%)

Omitted
Correct answer
D

51%
Answered correctly

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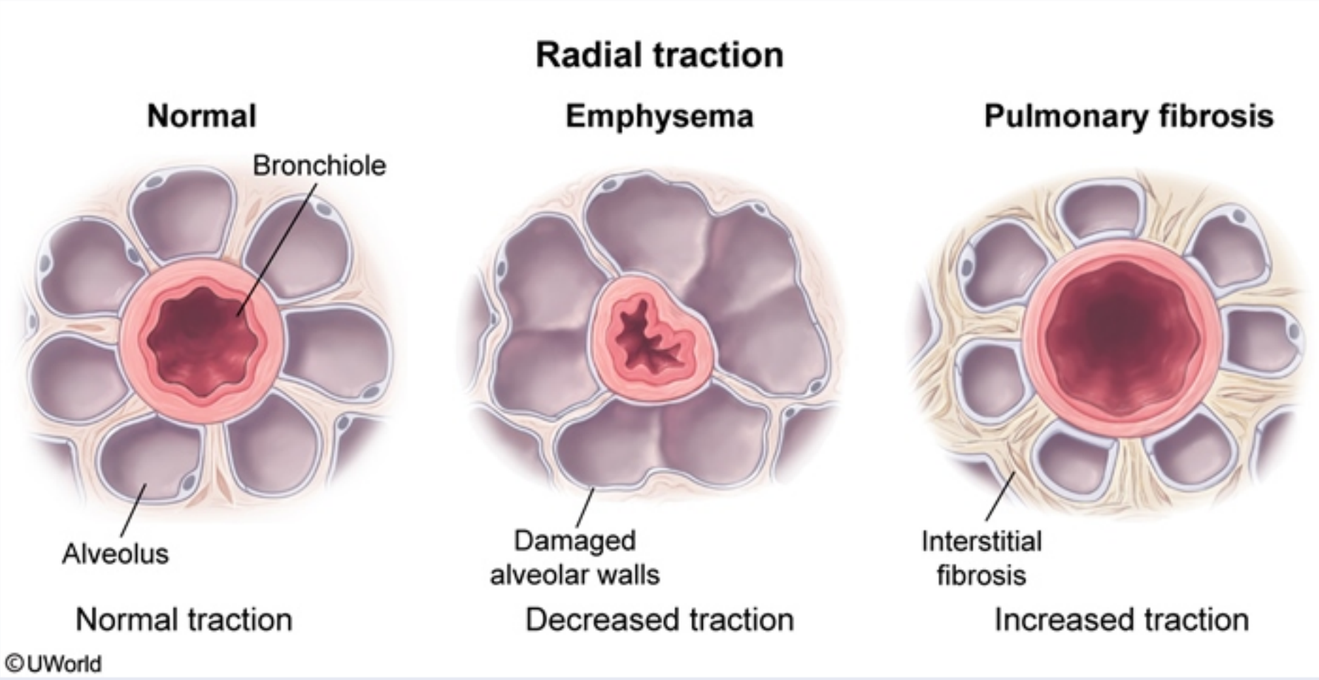
Time Spent

05/30/2020
Last Updated

Explanation

	Radial traction	
Normal	Emphysema	Pulmonary fibrosis



This patient's clinical presentation (progressive dyspnea, fine crackles, clubbing, diffuse reticular opacities) is consistent with **interstitial lung disease** (ILD). Most ILDs cause progressive **pulmonary fibrosis** with thickening and stiffening of the pulmonary interstitium. This causes increased lung elastic recoil, as well as **airway widening** due to increased outward pulling (**radial traction**) by the surrounding fibrotic tissue. The resulting decrease in airflow resistance leads to supernormal expiratory flow rates (higher than normal when corrected for lung volume).

Additional pulmonary function test findings in restrictive lung diseases include reduced total lung capacity, vital capacity, inspiratory capacity, functional residual capacity, and residual volume. The FVC and FEV1 are decreased as well. However, the FEV1/FVC ratio is typically normal or increased as FEV1 decreases less than FVC (due to airway widening relative to the low lung volumes). In addition, fibrosis causes a reduction in the diffusion capacity of carbon monoxide.

(Choice A) Lung compliance is defined as the change in lung volume for a given change in pressure. Increased compliance means that the lung

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This patient's clinical presentation (progressive dyspnea, fine crackles, clubbing, diffuse reticular opacities) is consistent with **interstitial lung disease** (ILD). Most ILDs cause progressive **pulmonary fibrosis** with thickening and stiffening of the pulmonary interstitium. This causes increased lung elastic recoil, as well as **airway widening** due to increased outward pulling (**radial traction**) by the surrounding fibrotic tissue. The resulting decrease in airflow resistance leads to supernormal expiratory flow rates (higher than normal when corrected for lung volume).

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(Choice A) Lung compliance is defined as the change in lung volume for a given change in pressure. Increased compliance means that the lung tissue stretches and expands more in response to increased pressure. Restrictive lung diseases cause decreased lung compliance and lower lung volumes due to interstitial fibrosis.

(Choice B) The outward recoil of the chest wall limits the volume of air that can be expired during maximal exhalation. An increase in outward chest wall recoil would decrease expiratory flow rates, as the respiratory muscles must work harder during expiration to oppose the increased outward force.

(Choice C) Physiological dead space refers to the volume of inspired air that does not participate in gas exchange. Changes in the amount of physiological dead space can affect alveolar ventilation but do not affect expiratory flow rates.

(Choice E) Thickening of the bronchioles, which occurs in some obstructive lung diseases (eg, asthma), leads to narrowing of the airways. Although reduced airway radius leads to local increase in airflow velocity, overall the increased resistance causes a decrease in expiratory flow rates. In fibrotic lung disease, the interstitium, not the bronchiolar walls, is thickened.

Educational objective:
Interstitial lung disease is associated with decreased lung volumes and increased lung elastic recoil caused by fibrotic interstitial tissue. The increased elastic recoil results in increased radial traction (outward pulling) on the airways, leading to increased expiratory flow rates when corrected for the low lung volume.

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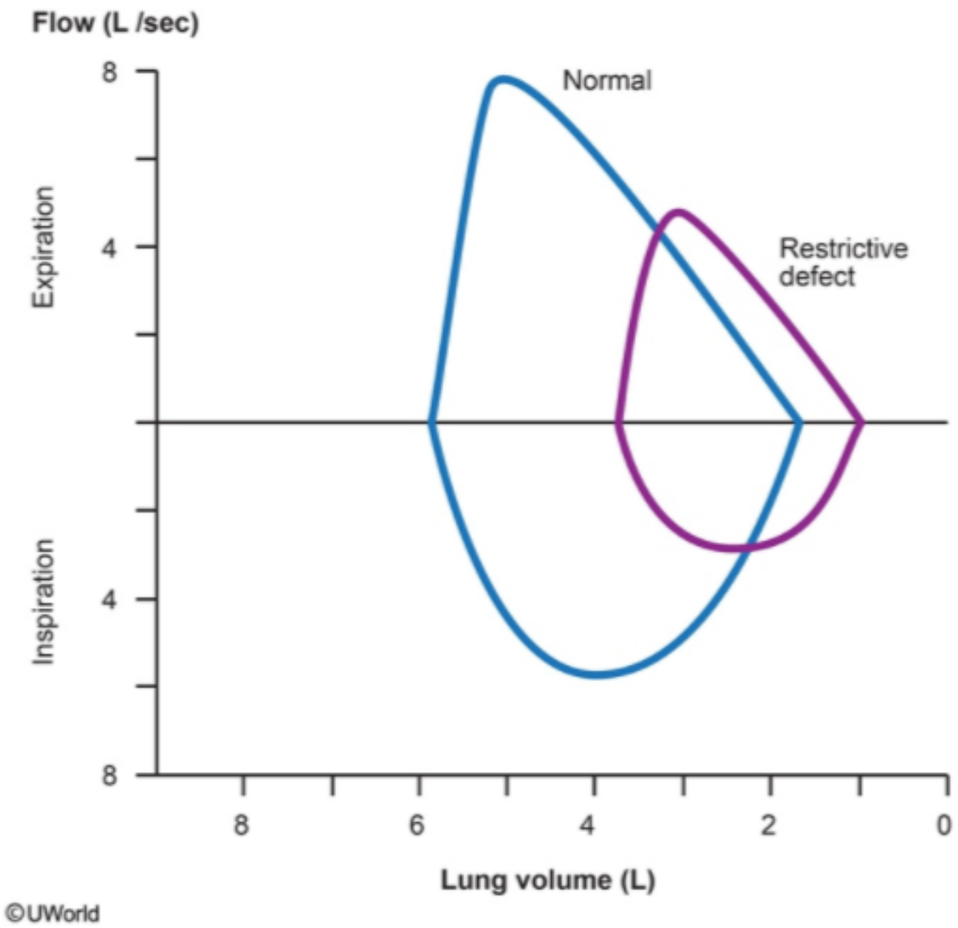

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corrected for the low lung volume.

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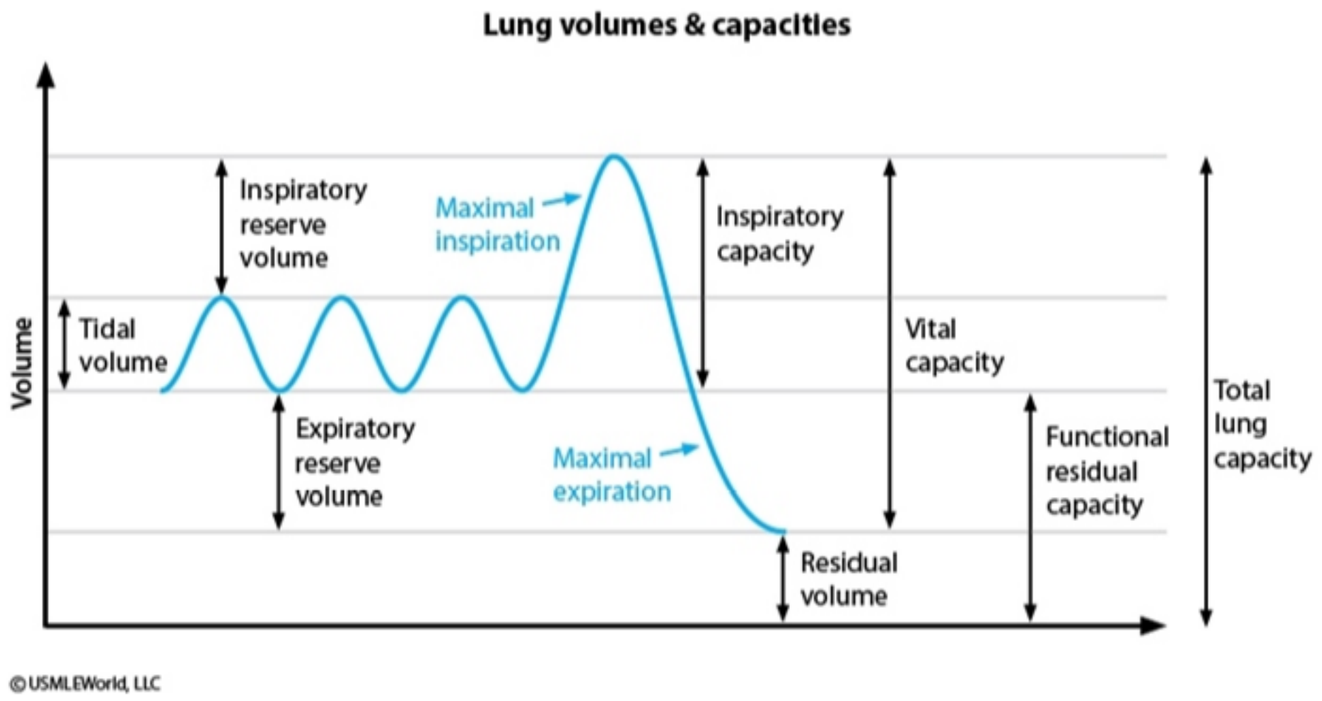

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corrected for the low lung volume.

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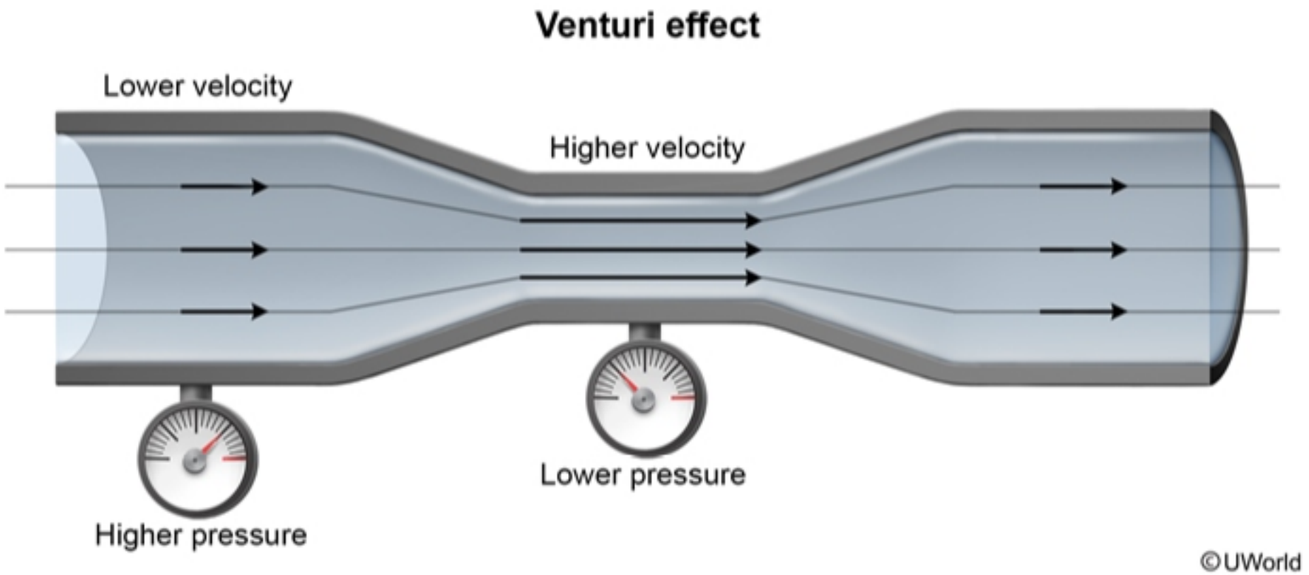

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A 21-year-old man is brought to the emergency department after being found unresponsive in a public restroom. He has a history of injection drug use. Temperature is 36.1 C (97 F), blood pressure is 110/70 mm Hg, pulse is 62/min, and respiratory rate is 8/min. On physical examination, the patient is unconscious with pinpoint pupils. Endotracheal intubation is performed, and mechanical ventilation is begun. The ventilator settings are adjusted to provide a minute ventilation of 6.0 L/min. Calculated alveolar ventilation is 4.2 L/min. Which of the following most likely accounts for the difference between these 2 parameters?

A. Dead space volume

B. Functional residual capacity

C. Residual volume

D. Respiratory rate

E. Tidal volume

Submit

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- ✓ A. Dead space volume (83%)
- B. Functional residual capacity (3%)
- C. Residual volume (6%)
- D. Respiratory rate (5%)
- E. Tidal volume (2%)

Omitted
Correct answer
A

83%
Answered correctly

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03/22/2020
Last Updated

Explanation

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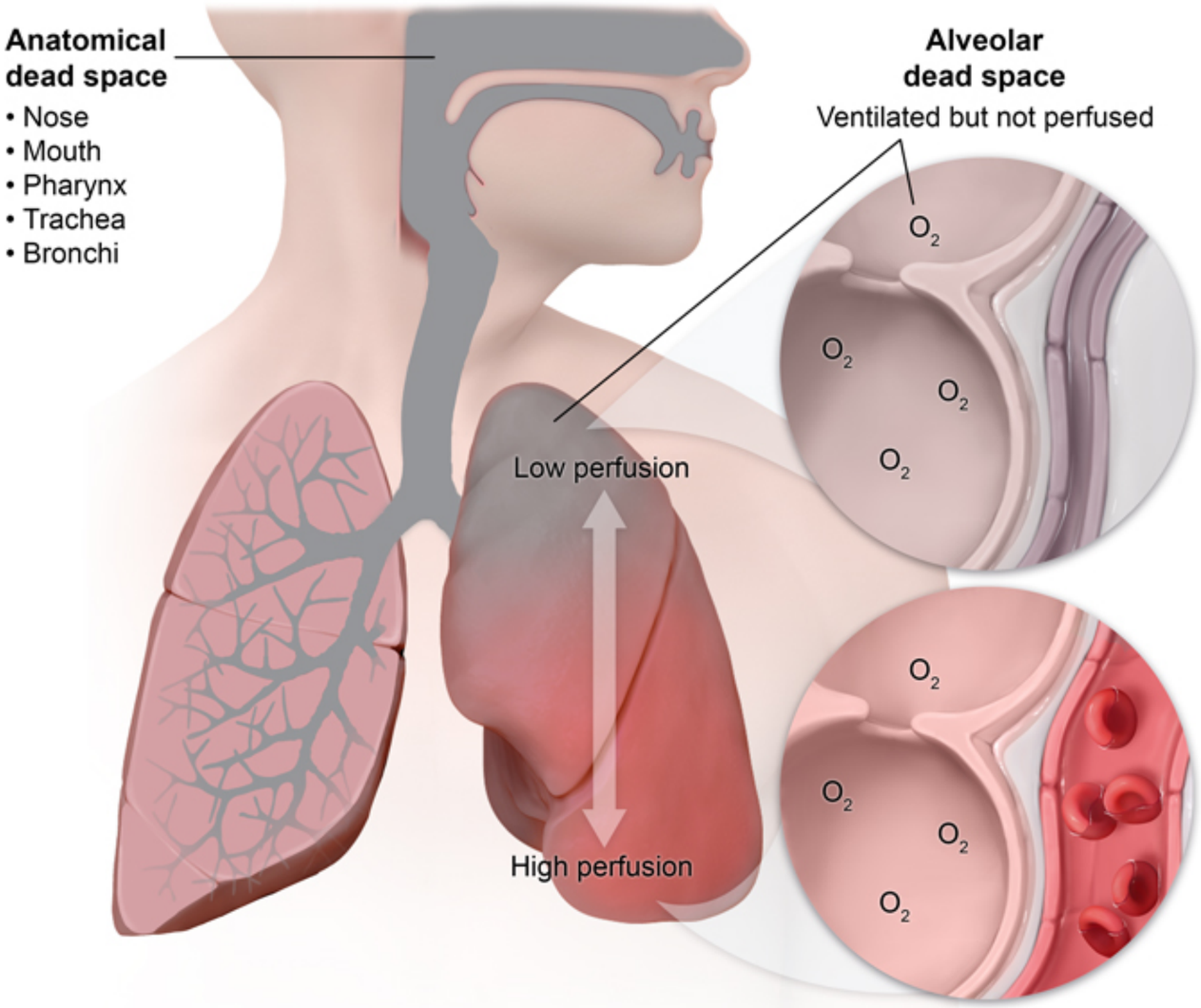
Dead space



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Minute ventilation is the **total volume of new air** that enters the respiratory pathways per minute. It can be calculated by multiplying the average tidal volume by the number of breaths per minute (minute ventilation [L/min] = tidal volume [L] x breaths/min).

Alveolar ventilation refers only to the **volume of new air reaching the gas exchange areas** (ie, alveoli and respiratory bronchioles) per minute. It can be calculated by **subtracting dead space volume** (which does not participate in gas exchange) **from the tidal volume**:

Alveolar ventilation (L/min) = (tidal volume − dead space volume) × breaths/min

The total volume of dead space in the lungs is known as physiologic dead space. It consists of both the **anatomic dead space** of the conducting airways (ie, nose, trachea, bronchi, bronchioles; normally ~150 mL) and alveolar dead space due to well-ventilated but poorly perfused alveoli. Because it is difficult to directly measure physiologic dead space, it is often estimated in mechanically ventilated patients by comparing arterial (a) and expiratory (E) pCO_2 levels:

Physiologic dead space = tidal volume × $([P_aCO_2 - P_ECO_2]/P_aCO_2)$

(Choices B and C) Functional residual capacity is the volume of air remaining in the lungs after a normal exhalation. It is the sum of residual volume (the volume of air remaining in the lungs after maximal exhalation) and expiratory reserve volume (the volume difference between normal end-expiration and maximal end-expiration).

(Choice D) Respiratory rate is the number of breaths taken per minute and is a factor in calculating both minute ventilation and alveolar ventilation.

(Choice E) Tidal volume is the volume of new air that enters the lungs with each normal, unforced breath. It is a factor in calculating both minute ventilation and alveolar ventilation.

Educational objective:
Minute ventilation is equal to the product of tidal volume and respiratory rate and includes dead space ventilation. Alveolar ventilation is equal to the product of respiratory rate and the difference between tidal volume and dead space volume.

Physiology Pulmonary & Critical Care Respiratory physiology

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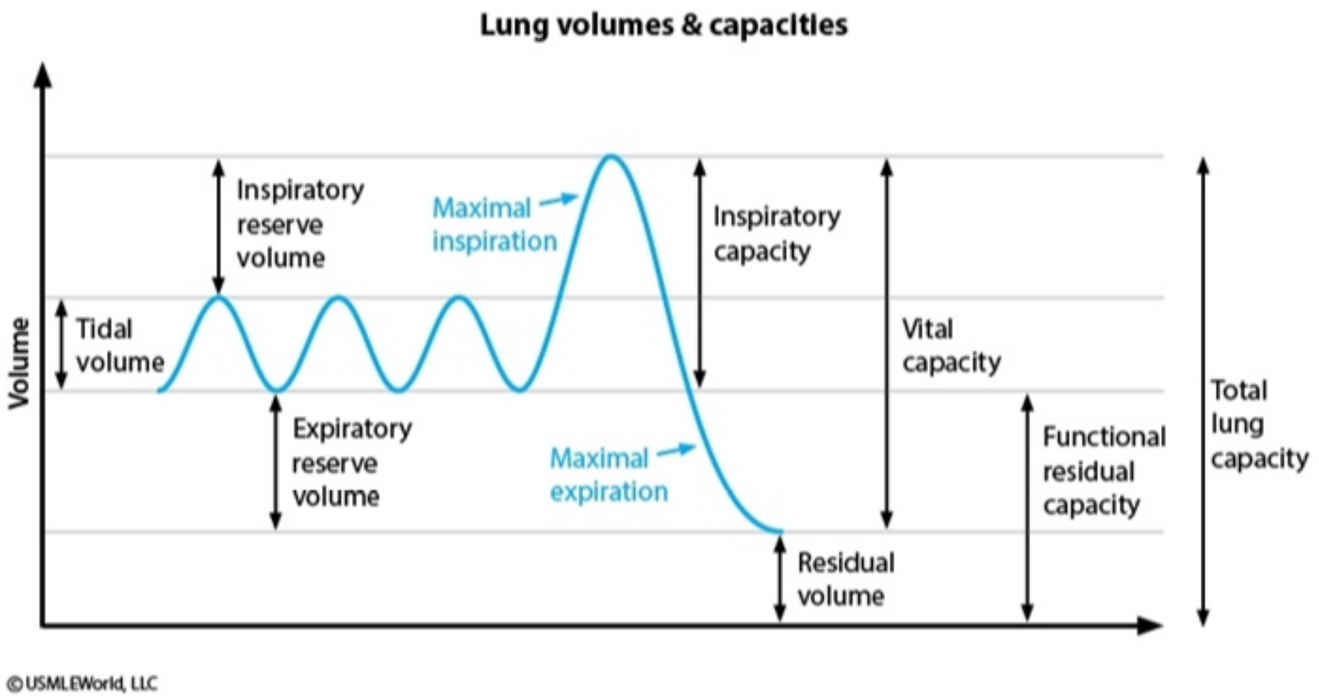

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A 20-year-old woman is brought to the emergency department by her boyfriend after being found unresponsive in her apartment. She has a medical history of major depression and generalized anxiety disorder. There is no evidence of trauma. On examination, the patient is obtunded and responds only to painful stimuli. There are no indications of recent vomiting. Lungs are clear to auscultation. Toxicology screen is positive for benzodiazepines. Which of the following sets of arterial blood gas findings (in mm Hg) are most likely present in this patient?

	PaO_2	$PaCO_2$	Alveolar-arterial O_2 gradient
A.	45	30	10
B.	45	30	30
C.	55	60	25
D.	55	60	10
E.	65	70	35

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	PaO_2	$PaCO_2$	Alveolar-arterial O_2 gradient
A. (2%)	45	30	10
B. (1%)	45	30	30
C. (13%)	55	60	25
✓ D. (76%)	55	60	10
E. (5%)	65	70	35

Omitted
Correct answer
D

76%
Answered correctly

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Time Spent

04/25/2020
Last Updated

Explanation

Causes of hypoxemia		
	Examples	**A-a gradient**
Reduced PiO_2	High altitude	Normal
Hypoventilation	CNS depression, morbid obesity	Normal
Diffusion limitation	Emphysema, ILD	Increased
V/Q mismatch*	Pulmonary embolism, pneumonia	Increased

*Caused by regional dead-space ventilation and/or intrapulmonary shunting.

A-a gradient = alveolar to arterial oxygen gradient; **ILD** = interstitial lung disease; **PiO_2** = partial pressure of inspired oxygen; **V/Q** = ventilation/perfusion ratio.

This patient has an **acute benzodiazepine overdose**. Benzodiazepines (eg, alprazolam, lorazepam) cause sedation and central respiratory depression with **hypoventilation** and **CO_2 retention**; therefore, affected patients have acute respiratory acidosis (low pH and $PaCO_2$ >40 mm Hg). Because full metabolic compensation by the kidneys (ie, HCO_3^- retention) requires approximately 72 hours, there is minimal compensation in the acute setting, and the expected serum HCO_3^- is near normal (24 mEq/L).

The alveolar-arterial **(A-a) O_2 gradient** is the difference between the partial pressure of alveolar oxygen (PAO_2) and the partial pressure of arterial oxygen (PaO_2); it represents the efficiency of gas transfer between the lungs and the circulation. A **small gradient** (eg, 4-15 mm Hg) is **normal** in part because there is physiologic shunting of unoxygenated bronchial blood, which decreases PaO_2. In addition to CO_2 retention, hypoventilation also causes **low PAO_2** that leads directly to hypoxemia (PaO_2 <75 mm Hg). The efficiency of gas transfer is intact and a **normal A-a O_2 gradient** is expected.

(Choice A) $PaCO_2$ <40 mm Hg indicates respiratory alkalosis. Respiratory alkalosis (ie, hyperventilation) with hypoxemia and a normal A-a O_2 gradient is expected at high altitude. The efficiency of gas transfer is intact, but low partial pressure of inspired oxygen (PiO_2) causes low PAO_2.

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(Choice A) $PaCO_2$ <40 mm Hg indicates respiratory alkalosis. Respiratory alkalosis (ie, hyperventilation) with hypoxemia and a normal A-a O_2 gradient is expected at high altitude. The efficiency of gas transfer is intact, but low partial pressure of inspired oxygen (PiO_2) causes low PAO_2.

(Choice B) Respiratory alkalosis with hypoxemia and an elevated A-a O_2 gradient is expected with lung pathology that causes acute V/Q mismatch (eg, pulmonary embolism and pneumonia).

(Choices C and E) Respiratory acidosis with hypoxemia and an elevated A-a O_2 gradient is expected with chronic obstructive pulmonary disease. These patients have chronic CO_2 retention, and O_2 exchange is impaired by emphysematous disruption of gas diffusion across the alveolar-capillary membrane.

Educational objective:
Acute benzodiazepine (eg, alprazolam, lorazepam) overdose causes central respiratory depression with hypoventilation. The hypoventilation leads to CO_2 retention and acute respiratory acidosis. It also decreases the PAO_2, leading directly to hypoxemia (PaO_2 <75 mm Hg). The efficiency of gas transfer between the lungs and the circulation is intact; therefore, a normal alveolar-arterial O_2 gradient (eg, <15 mm Hg) is expected.

Physiology	Pulmonary & Critical Care	Respiratory acidosis
Subject	System	Topic

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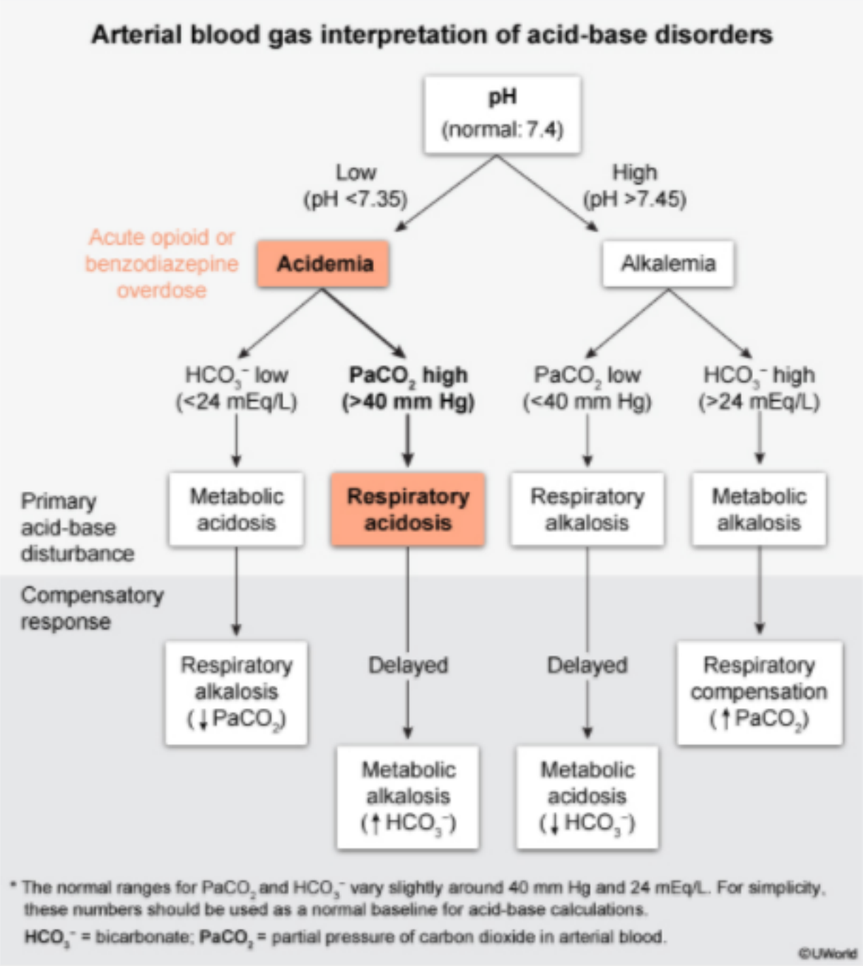

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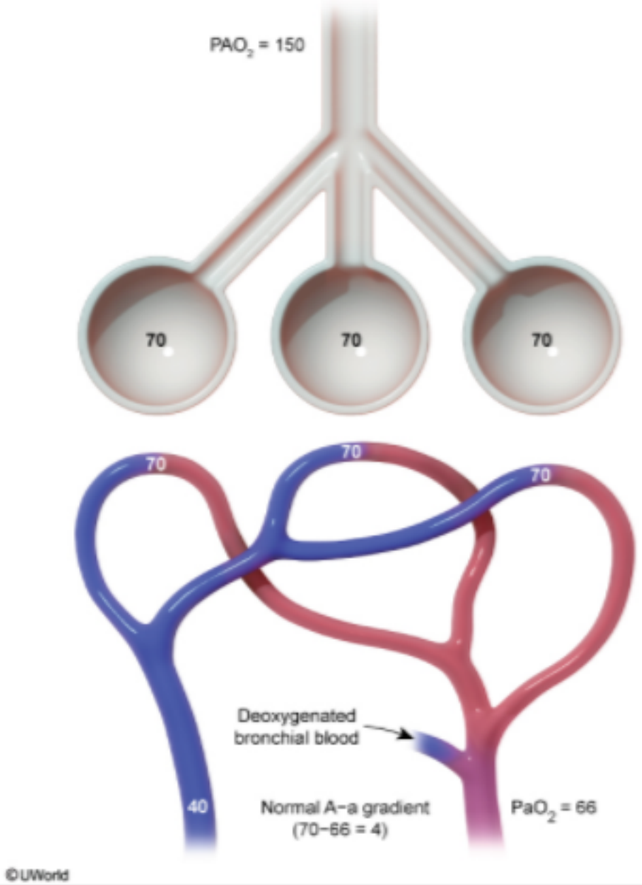
Alveolar hypoventilation



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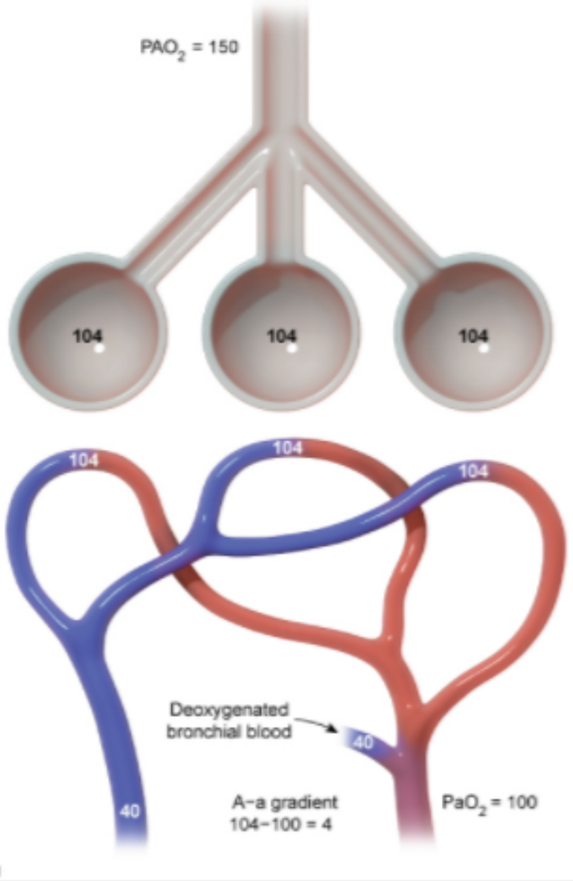
Normal bronchopulmonary shunting



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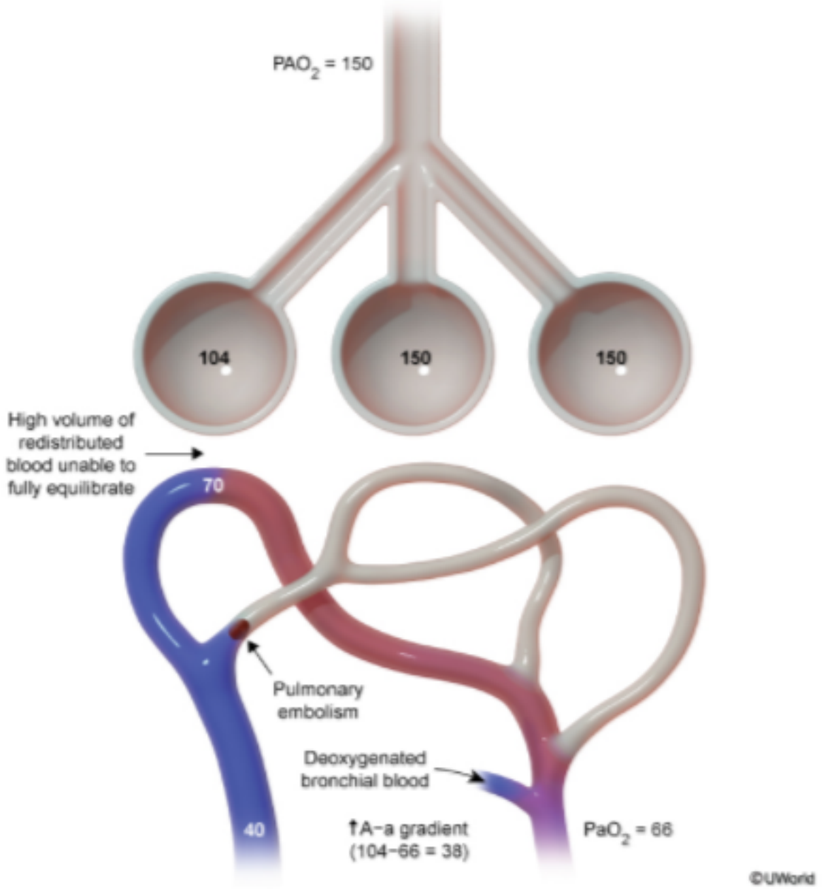
Dead space ventilation with V/Q mismatch



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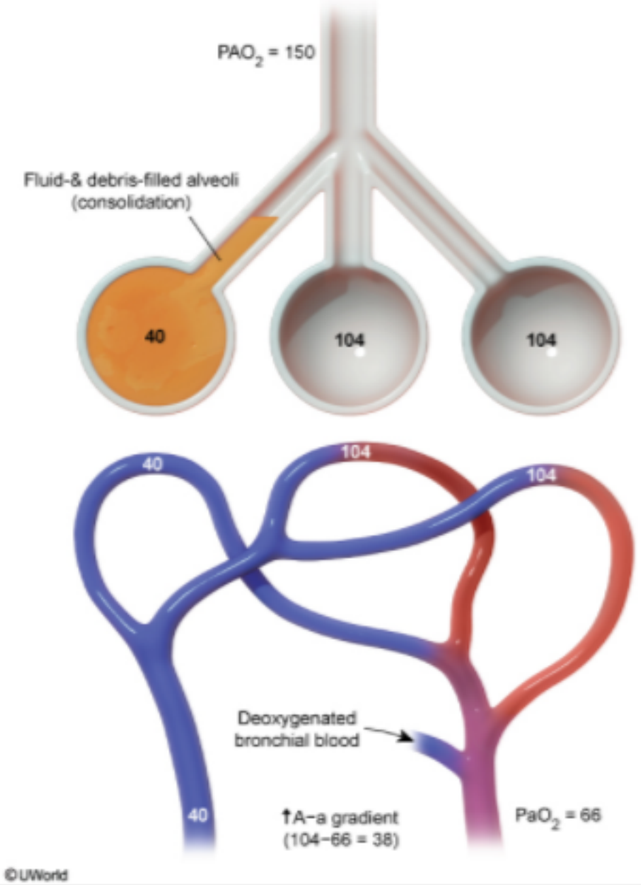
Intrapulmonary shunting with V/Q mismatch



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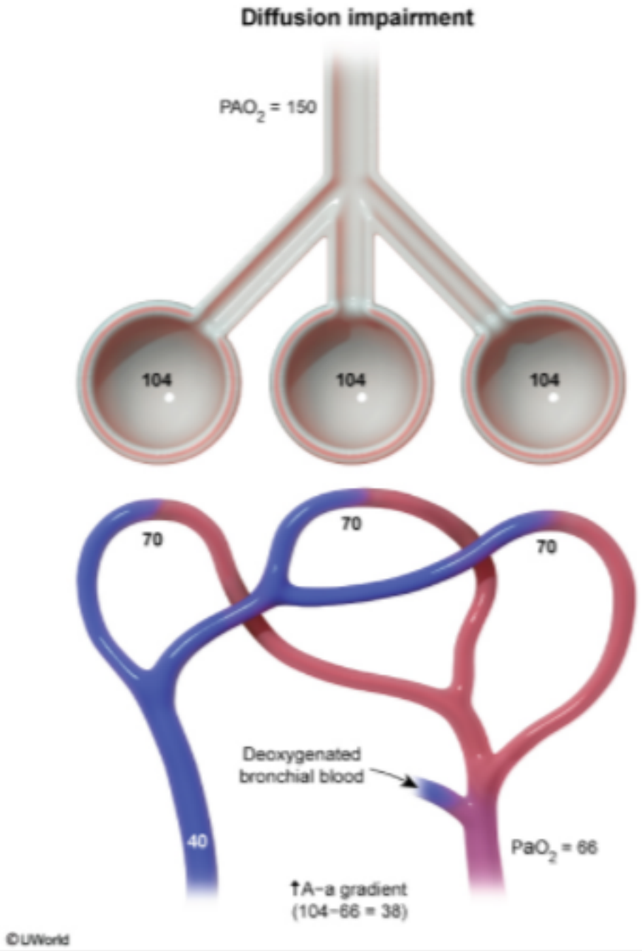

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Subject System Topic

A 44-year-old man comes to the emergency department due to sudden-onset shortness of breath that started a few hours ago. Last week, he sustained a crush injury after a motorcycle drove over his left foot, and he has been immobilized since then due to pain. The patient drinks alcohol occasionally and does not use tobacco or illicit drugs. Temperature is 36.1 C (97 F), blood pressure is 118/76 mm Hg, pulse is 102/min, and respirations are 28/min. BMI is 37 kg/m^2. On physical examination, heart rhythm is regular with normal S1 and S2. The lungs are clear to auscultation bilaterally. The dorsum of the left foot has resolving ecchymoses and swelling compared to when he was evaluated last week. The right calf is swollen and tender. Which of the following arterial blood gas values are most likely to be present in this patient?

	pH	PaO_2 (mm Hg)	$PaCO_2$ (mm Hg)	Serum HCO_3^- (mEq/L)
A.	7.30	101	23	11
B.	7.32	60	64	32
C.	7.38	80	40	23
D.	7.57	65	26	23
E.	7.47	96	24	17
F.	7.49	75	49	36

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B. (21%)	7.32	60	64	32
C. (8%)	7.38	80	40	23
✓ D. (44%)	7.57	65	26	23
E. (15%)	7.47	96	24	17
F. (3%)	7.49	75	49	36

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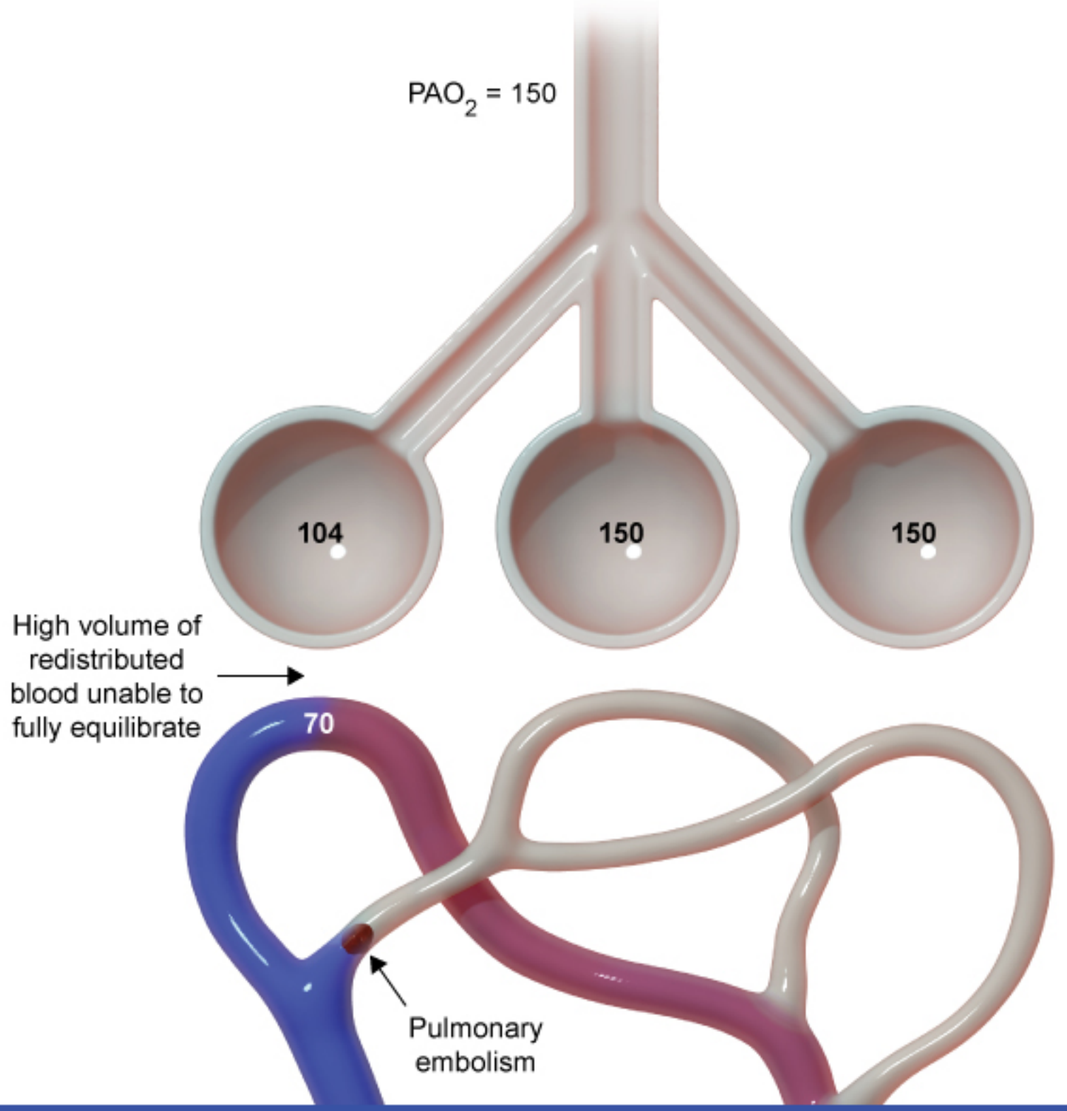
Pulmonary embolism



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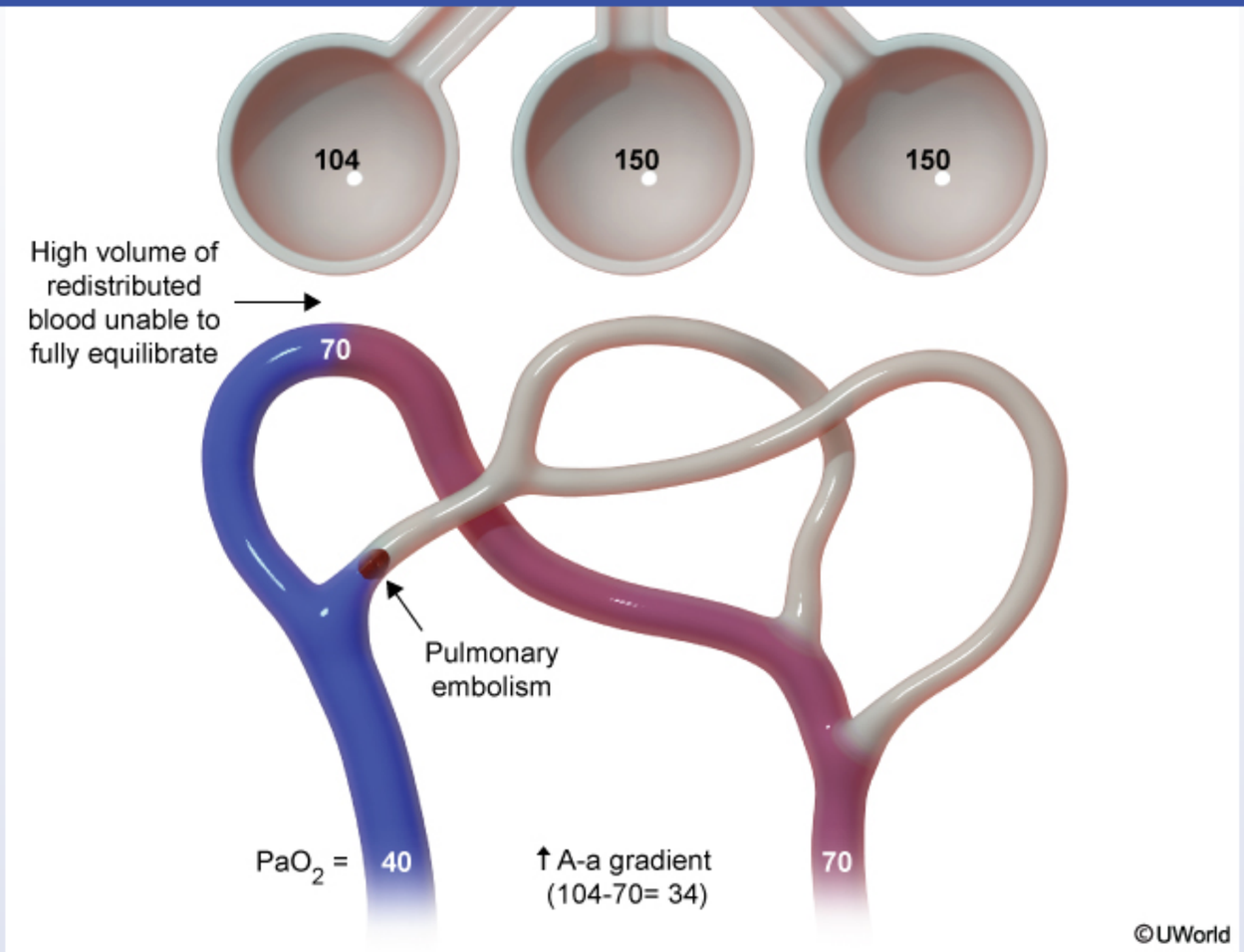

Sudden-onset **dyspnea** in the setting of recent **calf swelling** is strongly suggestive of **pulmonary embolism (PE)**. Dyspnea is the most common symptom of PE and risk factors include obesity, smoking, and prolonged immobilization. The embolus typically arises from a deep venous thrombus in the lower extremities (causes calf swelling) and lodges itself within the arterial blood supply of the lungs.

PE occludes or significantly reduces blood flow to a portion of the pulmonary parenchyma, resulting in increased **dead space ventilation** and

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PE occludes or significantly reduces blood flow to a portion of the pulmonary parenchyma, resulting in increased **dead space ventilation** and redistribution of pulmonary blood flow away from the affected segments. This leads to increased **ventilation/perfusion (V/Q) mismatch** in the remainder of the lungs with consequent **hypoxemia**.

Stimulation of central respiratory drive occurs in response to dyspnea and inflammatory mediators released by ischemic pulmonary tissue. **Hyperventilation** does not significantly improve arterial oxygenation because hemoglobin is nearly fully saturated with O_2 in areas of normal V/Q ratio, allowing little capacity for high V/Q regions to increase blood O_2 content much further. In contrast, CO_2 removal is more directly dependent on ventilation, and high V/Q regions have large capacity to **exhale additional CO_2**. Therefore, the hyperventilation leads to hypocapnia (low $PaCO_2$) and **respiratory alkalosis**. The serum HCO_3^- is near normal in the acute setting, but metabolic compensation with renal bicarbonate loss takes place over the next 72 hours.

(Choice A) Low blood pH of 7.30 with low serum HCO_3^- indicates metabolic acidosis, which is compensated by hyperventilation leading to low $PaCO_2$.

(Choice B) A low pH of 7.32 with high $PaCO_2$ reflects respiratory acidosis. The high HCO_3^- indicates renal compensation by bicarbonate retention. Although PE may eventually lead to respiratory collapse with an acute increase in $PaCO_2$, a renal compensatory response would not be expected so abruptly.

(Choice C) These arterial blood gas values are considered normal, reflecting an absence of acid-base disturbance.

(Choice E) A high pH of 7.47 with low $PaCO_2$ reflects respiratory alkalosis. The low HCO_3^- indicates renal compensation, which is expected with chronic respiratory alkalosis but should not be present with acute PE. Normal PaO_2 can occasionally be present in acute PE but is less likely.

(Choice F) A high pH of 7.48 with high serum HCO_3^- reflects metabolic alkalosis, which is compensated by hypoventilation leading to high $PaCO_2$.

remainder of the lungs with consequent **hypoxemia**.

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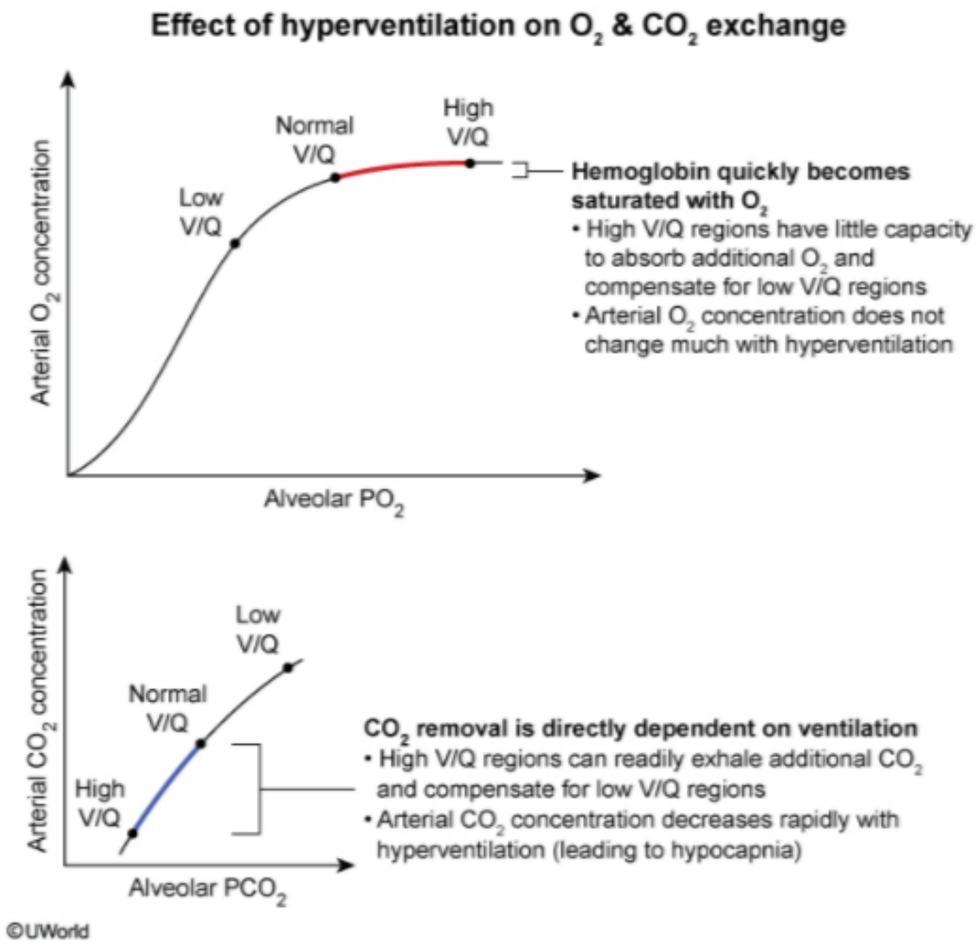

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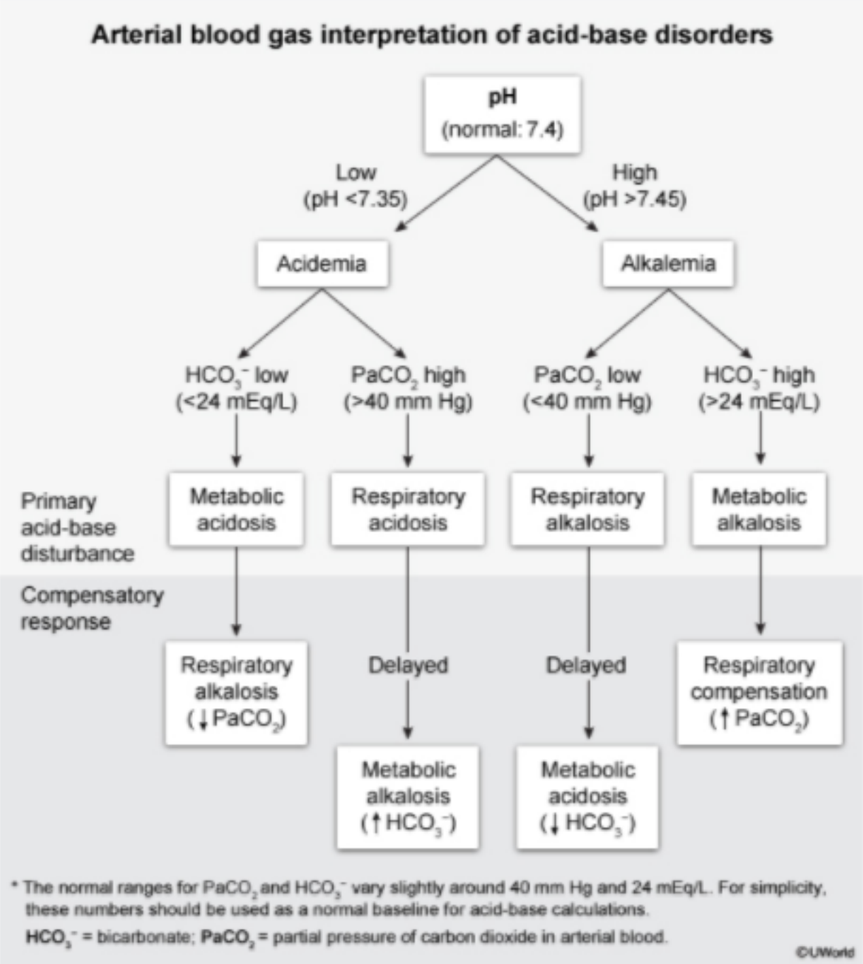

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Educational objective:
The combination of calf swelling, history of prolonged immobility, and sudden-onset dyspnea is strongly suggestive of acute pulmonary embolism (PE). PE typically presents with hypoxemia due to ventilation/perfusion mismatch and acute respiratory alkalosis (hypocapnia) due to hyperventilation.

References

- Hypoxemia in acute pulmonary embolism.
- Mechanisms of hypoxemia and hypocapnia in pulmonary embolism.

Physiology	Pulmonary & Critical Care	Pulmonary embolism
Subject	System	Topic

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A 30-year-old woman who normally resides in Florida (elevation near sea level) plans to travel to La Paz, Bolivia (elevation 3,600 m [11,900 ft]) for a week-long business trip. Medical history is unremarkable. Which of the following physiologic changes are expected during the patient's week in La Paz?

	Plasma volume	Pulmonary arterial resistance	Cardiac output
A.	↓	↓	↓
B.	↓	↓	↑
C.	↓	↑	↑
D.	↑	↓	↓
E.	↑	↑	↓

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	Plasma volume	Pulmonary arterial resistance	Cardiac output
A. (1%)	↓	↓	↓
B. (17%)	↓	↓	↑
✓ C. (52%)	↓	↑	↑
D. (5%)	↑	↓	↓
E. (22%)	↑	↑	↓

Omitted
Correct answer
C

52%
Answered correctly

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Explanation

Physiologic responses to high altitude	
Lungs	• Hypoxic vasoconstriction → ↑ PVR & PAP • ↑ minute ventilation → ↑ PaO_2 & ↓ $PaCO_2$
Kidneys	• ↑ erythropoietin production • ↑ HCO_3^- excretion (compensatory metabolic acidosis) • Aldosterone suppression with diuresis & ↓ plasma volume
Blood	• ↑ 2,3-biphosphoglycerate → ↑ O_2 unloading in tissues • Upregulation of HIF → erythropoiesis & angiogenesis • ↑ hemoglobin concentration (O_2-carrying capacity)
Heart	• ↑ heart rate & slightly ↑ cardiac output
Brain	• Vasodilation with ↑ cerebral blood flow

HIF = hypoxia inducible factor; **PAP** = pulmonary arterial pressure; **PVR** = pulmonary vascular resistance.

The decreased atmospheric pressure at **high altitude** (eg, >2,500 m [~8,000 ft]) reduces the partial pressure of inspired oxygen (PiO_2). Such an environment stimulates an array of **physiologic responses** aimed at maintaining adequate O_2 delivery to the tissues. The initial responses to high altitude include:

- Peripheral chemoreceptors in the aorta and carotid body stimulate **hyperventilation** in an effort to increase arterial oxygenation (PaO_2). The hyperventilation also increases CO_2 removal to decrease $PaCO_2$ and cause respiratory alkalosis. The alkalosis initially shifts the hemoglobin dissociation curve to the left to increase O_2 uptake in the lungs.
- Hypoxic pulmonary vasoconstriction occurs to minimize ventilation-perfusion mismatching and optimize pulmonary O_2 uptake. This leads to **increased pulmonary vascular resistance**, which increases pulmonary arterial pressure.
- Sympathetic activity is increased, leading to **increased heart rate and cardiac output**.

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- Hypoxic pulmonary vasoconstriction occurs to minimize ventilation-perfusion mismatching and optimize pulmonary O_2 uptake. This leads to **increased pulmonary vascular resistance**, which increases pulmonary arterial pressure.
- Sympathetic activity is increased, leading to **increased heart rate and cardiac output**.
- Despite the drop in $PaCO_2$ (which encourages cerebral vasoconstriction), reduced PaO_2 and marked tissue hypoxia lead to overall cerebral vasodilation to increase cerebral blood flow.

Additional responses occur over the next 24-48 hours:

- The kidneys increase HCO_3^- excretion (compensatory metabolic acidosis), which decreases blood pH. Because central chemoreceptors inhibit ventilation when pH gets too high, the HCO_3^- excretion allows for additional hyperventilation.
- Hypoxemia suppresses aldosterone activity, which together with increased HCO_3^- excretion results in diuresis and total body volume loss. The **reduced plasma volume** increases hematocrit and also reduces cardiac preload to decrease myocardial O_2 demand. There is a resulting decrease in stroke volume, but cardiac output remains slightly increased from baseline due to increased heart rate.
- Red blood cells increase production of 2,3-biphosphoglycerate to shift the hemoglobin dissociation curve back to the right and facilitate O_2 unloading in the tissues. In addition, the kidneys increase secretion of erythropoietin. There is also upregulation of hypoxia inducible factor (HIF) in cells throughout the body. HIF stimulates erythropoiesis as well as increased angiogenesis in skeletal muscle and other tissues to improve O_2 delivery.

Individuals who remain at high altitude for an extended period will experience the full benefit of increased erythropoietin secretion and upregulation of HIF, as secondary polycythemia (increased O_2 carrying capacity) and angiogenesis are maximized after several weeks.

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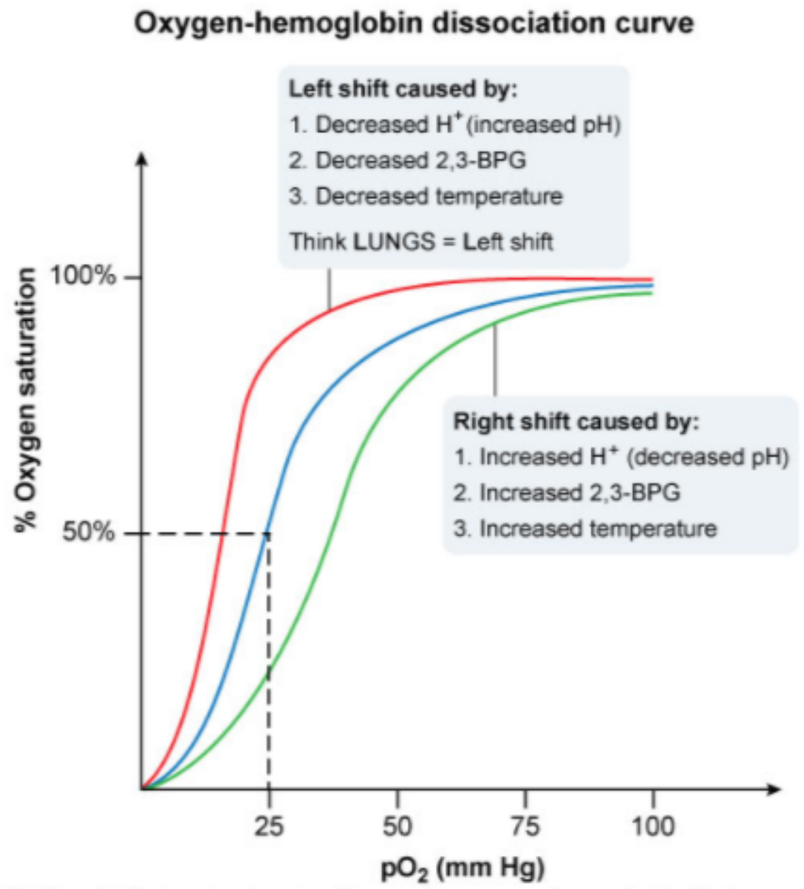

2,3-BPG = 2,3-bisphosphoglycerate; pO_2 = partial pressure of oxygen in the blood.

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vasodilation to increase cerebral blood flow.

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Individuals who remain at high altitude for an extended period will experience the full benefit of increased erythropoietin secretion and upregulation of HIF, as secondary polycythemia (increased O_2 carrying capacity) and angiogenesis are maximized after several weeks.

Educational objective:
An array of physiologic responses takes place to maintain adequate O_2 delivery to the tissues in the hypoxic environment at high altitude. These include hypoxic pulmonary vasoconstriction (increased pulmonary vascular resistance), increased sympathetic activity to increase cardiac output, and aldosterone suppression to reduce plasma volume.

References

- Human responses to extreme altitudes.

Physiology	Pulmonary & Critical Care	High altitude illness
Subject	System	Topic

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Researchers are studying the structure and function of hemoglobin. Arterial and venous blood samples are obtained from enrolled volunteers with no health problems. Red blood cells are isolated from whole blood by differential centrifugation, and the contents of the intact red blood cells are analyzed. It is found that the concentration of chloride is much lower in the red blood cells in the arterial sample compared to the venous sample. The activity of which of the following enzymes is most likely responsible for the observed finding?

A. Bisphosphoglycerate mutase

B. Carbonic anhydrase

C. Glucose-6-phosphate dehydrogenase

D. Na^+-K^+ ATPase

E. Pyruvate kinase

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A. Bisphosphoglycerate mutase (8%)

✓ B. Carbonic anhydrase (75%)

C. Glucose-6-phosphate dehydrogenase (3%)

D. Na^+-K^+ ATPase (11%)

E. Pyruvate kinase (1%)

Omitted
Correct answer
B

75%
Answered correctly

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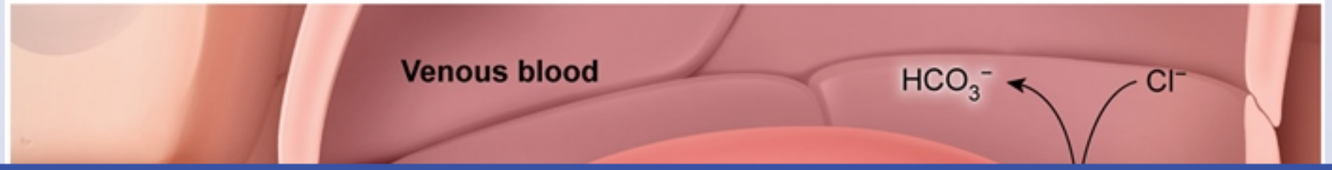
Last Updated

Explanation

Red blood cell chloride shifting



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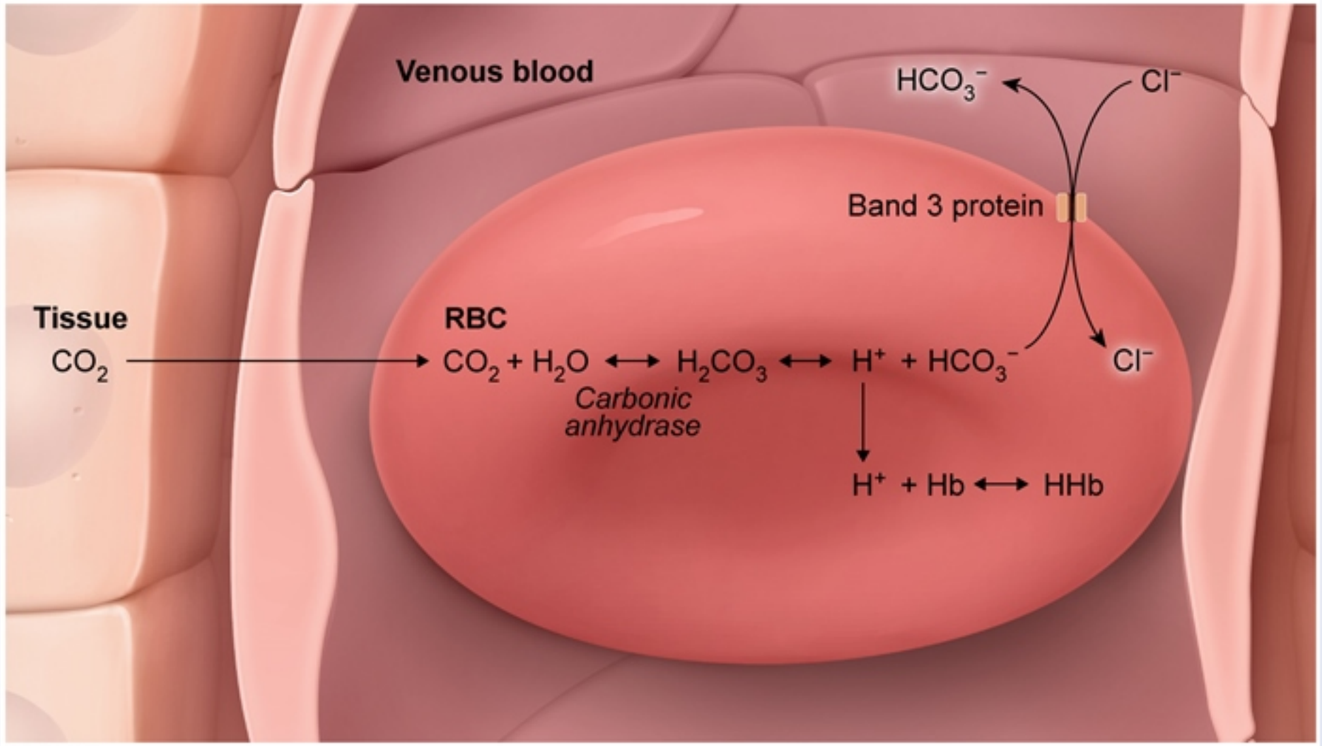

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Hemoglobin is only found within **red blood cells** (RBCs), and it is responsible not only for O_2 delivery to the tissues, but also for carrying CO_2 from the tissues to the lungs. Hemoglobin carries CO_2 in the form of carbaminohemoglobin, which is created as follows:

$$CO_2 + Hb\text{-}NH_3 = 2H^+ + Hb\text{-}NH\text{-}CO_2$$

However, only a small percentage of total blood CO_2 is carried by hemoglobin. The majority of total **blood CO_2** is **carried in the plasma** as **bicarbonate ion (HCO_3^-)** via the following process:

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However, only a small percentage of total blood CO_2 is carried by hemoglobin. The majority of total **blood CO_2** is **carried in the plasma** as **bicarbonate ion (HCO_3^-)** via the following process:

- The CO_2 produced by tissue metabolism enters RBCs and is hydrated by the enzyme **carbonic anhydrase** to form carbonic acid (H_2CO_3).
- H_2CO_3 then undergoes spontaneous conversion to HCO_3^- and H^+.
- The excess HCO_3^- is then transferred out of RBCs into the plasma via **band 3 protein** in exchange for chloride ions (Cl^-) to maintain electrical neutrality. This exchange is known as "**chloride shift**" and is the principal cause of high RBC chloride content in venous blood.

(Choice A) Bisphosphoglycerate (BPG) mutase converts 1,3-BPG to 2,3-BPG. In RBCs, 2,3-BPG combines with hemoglobin to decrease its affinity for O_2 and facilitate O_2 unloading in the tissues.

(Choices C and E) Glucose-6-phosphate dehydrogenase is the first enzyme in the pentose phosphate pathway (produces NADPH) and pyruvate kinase catalyzes the final step of glycolysis (produces ATP). Deficiency of either glucose-6-phosphate dehydrogenase or pyruvate kinase typically leads to shortened RBC lifespan and episodic hemolysis triggered by oxidative stressors.

(Choice D) Na^+/K^+-ATPase is responsible for the maintenance of ionic concentration gradients across the plasma membrane in many cells in the body. This energy-requiring pump is electrogenic as it extrudes 3 sodium ions for every 2 potassium ions that enter the cell, which creates negative intracellular potential.

Educational objective:
The majority of CO_2 produced in the tissues is transported to the lungs as bicarbonate ion (HCO_3^-). Within red blood cells (RBCs), the enzyme carbonic anhydrase forms HCO_3^- from CO_2 and water. The excess HCO_3^- is then transferred out of RBCs into the plasma via exchange with chloride ions (Cl^-). This exchange is known as "chloride shift" and is the principal cause of high RBC chloride content in venous blood.

Physiology Pulmonary & Critical Care Respiratory physiology

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- The excess HCO_3^- is then transferred out of RBCs into the plasma via **band 3 protein** in exchange for chloride ions (Cl^-) to maintain electrical neutrality. This exchange is known as "**chloride shift**" and is the principal cause of high RBC chloride content in venous blood.

(Choice A) Bisphosphoglycerate (BPG) mutase converts 1,3-BPG to 2,3-BPG. In RBCs, 2,3-BPG combines with hemoglobin to decrease its affinity for O_2 and facilitate O_2 unloading in the tissues.

(Choices C and E) Glucose-6-phosphate dehydrogenase is the first enzyme in the pentose phosphate pathway (produces NADPH) and pyruvate kinase catalyzes the final step of glycolysis (produces ATP). Deficiency of either glucose-6-phosphate dehydrogenase or pyruvate kinase typically leads to shortened RBC lifespan and episodic hemolysis triggered by oxidative stressors.

(Choice D) Na^+/K^+-ATPase is responsible for the maintenance of ionic concentration gradients across the plasma membrane in many cells in the body. This energy-requiring pump is electrogenic as it extrudes 3 sodium ions for every 2 potassium ions that enter the cell, which creates negative intracellular potential.

Educational objective:
The majority of CO_2 produced in the tissues is transported to the lungs as bicarbonate ion (HCO_3^-). Within red blood cells (RBCs), the enzyme carbonic anhydrase forms HCO_3^- from CO_2 and water. The excess HCO_3^- is then transferred out of RBCs into the plasma via exchange with chloride ions (Cl^-). This exchange is known as "chloride shift" and is the principal cause of high RBC chloride content in venous blood.

Physiology	Pulmonary & Critical Care	Respiratory physiology
Subject	System	Topic

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A 6-year-old boy playing in a dusty field in windy weather inhales many small particles that become lodged in his terminal bronchioles. Which of the following respiratory components is most important in clearing these particles?

A. Ciliated cells
B. Goblet cells
C. Macrophages
D. Submucosal glands
E. Type I pneumocytes
F. Type II pneumocytes

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A 6-year-old boy playing in a dusty field in windy weather inhales many small particles that become lodged in his terminal bronchioles. Which of the following respiratory components is most important in clearing these particles?

- ✓ A. Ciliated cells (58%)
- B. Goblet cells (4%)
- C. Macrophages (32%)
- D. Submucosal glands (0%)
- E. Type I pneumocytes (1%)
- F. Type II pneumocytes (2%)

Omitted
Correct answer
A

58%
Answered correctly

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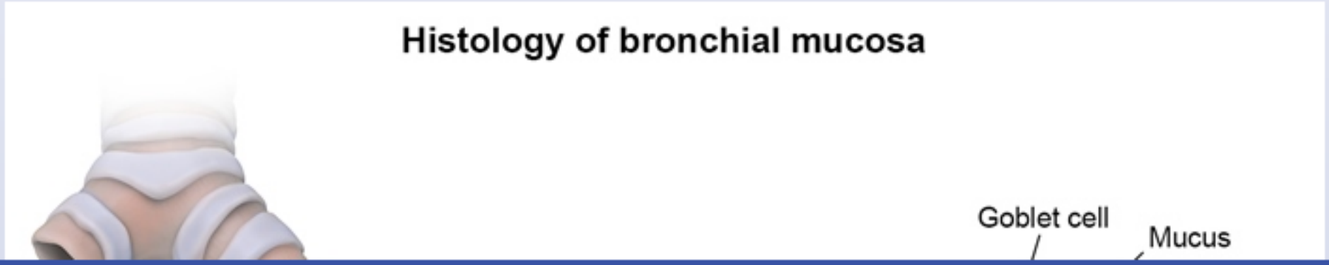
05/07/2020
Last Updated

Explanation



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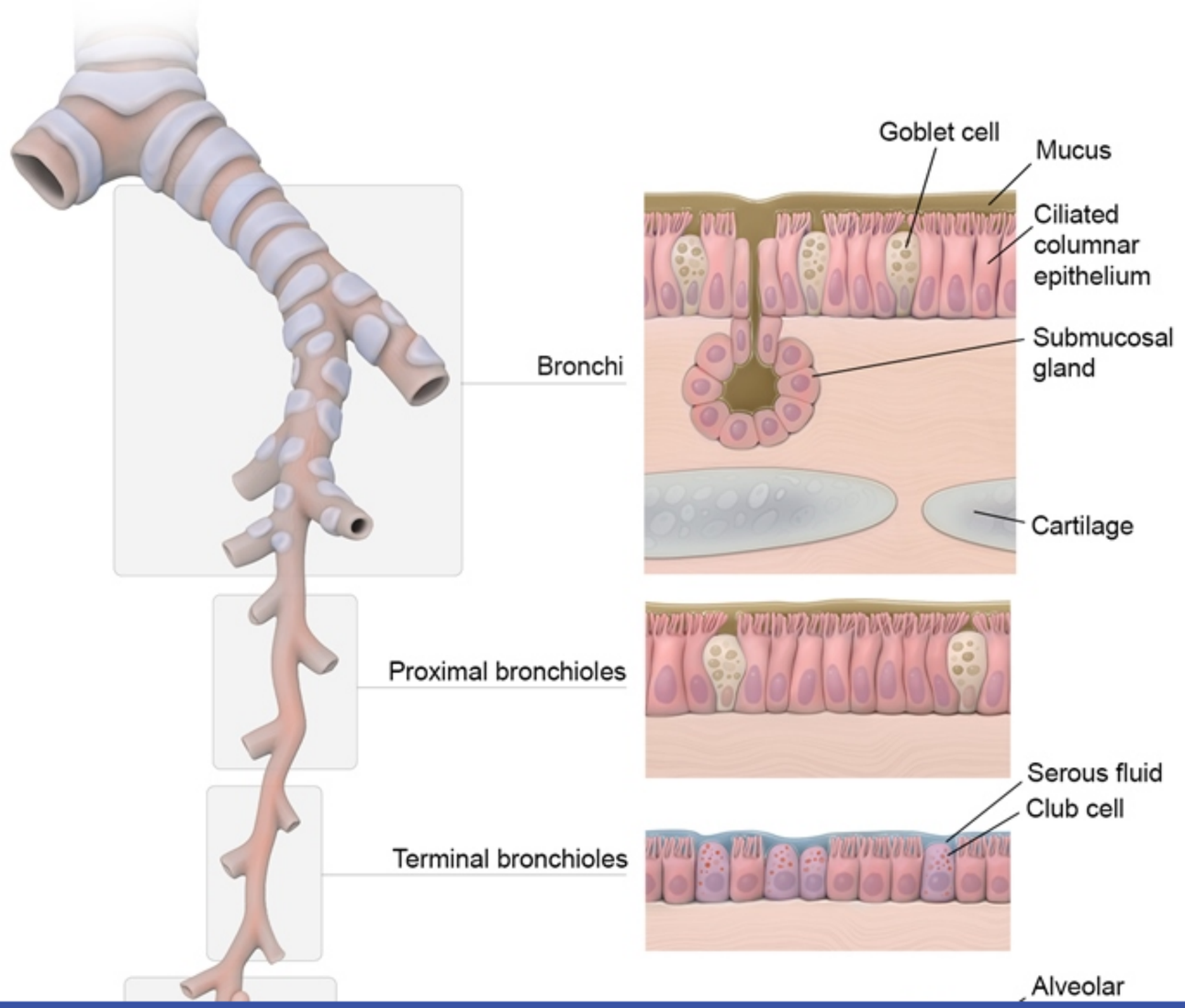
Histology of bronchial mucosa



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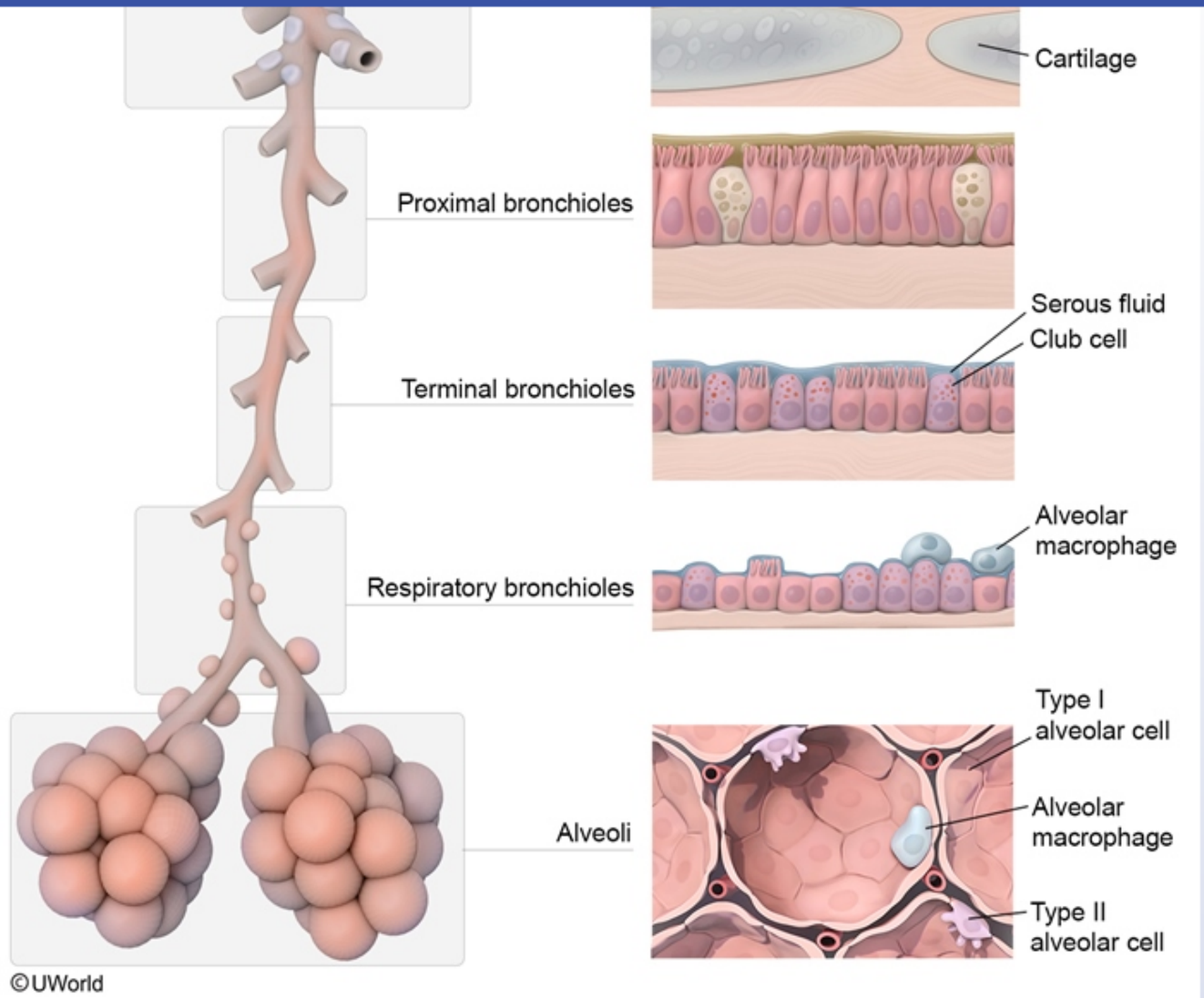

Mucociliary clearance is responsible for removing the vast majority of inhaled particles that lodge within the bronchial tree. **Ciliated mucosal epithelium** lines the pulmonary airways from the trachea to the proximal portions of the respiratory bronchioles. Mucus and fluid secreted onto

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Mucociliary clearance is responsible for removing the vast majority of inhaled particles that lodge within the bronchial tree. **Ciliated mucosal epithelium** lines the pulmonary airways from the trachea to the proximal portions of the respiratory bronchioles. Mucus and fluid secreted onto this epithelial surface act to trap particles suspended in the inspired air. The trapped particles are constantly swept upward from the bronchioles toward the pharynx by cilia that collectively beat in the direction of the pharynx. The mucus and debris are then swallowed or expectorated upon reaching the pharynx.

The **terminal bronchioles** are covered by ciliated cuboidal epithelium and club cells, which help with mucociliary clearance in this region.

(Choice B) Goblet cells are mucus-secreting cells that are interspersed throughout the respiratory mucosa from the trachea down to the larger bronchioles. However, they are not found within the terminal bronchioles. This region is lined by a surfactant-containing fluid secreted by club cells that is continuous with the more proximal mucous layer.

(Choice C) Clearance of particles that lodge distal to the terminal bronchioles is dependent on phagocytosis by alveolar macrophages. These cells can destroy some inhaled particles (eg, bacteria) by lysosomal degradation. Nondigestible material must be transported by macrophages to the pulmonary lymphatics or to the terminal bronchioles (for clearance by the mucociliary system).

(Choice D) Submucosal mucous and mucoserous glands help form the mucous layer in the larger airways. They are found within the trachea and bronchi but not in the bronchioles.

(Choices E and F) Type I and type II pneumocytes line the alveolar ducts and alveoli. Type I pneumocytes are thin cells stretched across the alveolar wall that mediate gas exchange. Type II pneumocytes produce surfactant and divide and differentiate into type I pneumocytes to replace damaged cells.

Educational objective:
Most inhaled particles that lodge in the bronchial tree are removed via proximal transport by ciliated epithelial cells (mucociliary clearance). Mucus-secreting cells are present to the level of the larger bronchioles, after which club cells become the prominent secretory cell type.

Physiology	Pulmonary & Critical Care	Respiratory mucosa
Subject	System	Topic

epithelium lines the pulmonary airways from the trachea to the proximal portions of the respiratory bronchioles. Mucus and fluid secreted onto this epithelial surface act to trap particles suspended in the inspired air. The trapped particles are constantly swept upward from the bronchioles toward the pharynx by cilia that collectively beat in the direction of the pharynx. The mucus and debris are then swallowed or expectorated upon reaching the pharynx.

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Physiology	Pulmonary & Critical Care	Respiratory mucosa
Subject	System	Topic

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A 45-year-old hospitalized man is evaluated for shortness of breath and hypoxemia. The patient was admitted 3 days ago after a motor vehicle collision. At that time, evaluation revealed a femur fracture but no other injuries, and the patient underwent open reduction and internal fixation of the fracture. This morning, he suddenly began experiencing shortness of breath and sharp chest pain. The patient has no significant medical history and has been receiving morphine for pain control. He has smoked a pack of cigarettes daily for 15 years and drinks alcohol occasionally. Temperature is 36.1 C (97 F), blood pressure is 120/70 mm Hg, and pulse is 98/min. BMI is 42 kg/m^2. Chest x-ray is unremarkable, and arterial blood gas analysis on room air shows a pH of 7.51, $PaCO_2$ of 30 mm Hg, and PaO_2 of 65 mm Hg. Which of the following is the primary cause of hypoxemia in this patient?

- A. Alveolar hypoventilation
- B. Decreased blood oxygen-carrying capacity
- C. Increased tissue oxygen extraction
- D. Primary diffusion impairment
- E. Ventilation/perfusion mismatch

Submit

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- A. Alveolar hypoventilation (6%)
- B. Decreased blood oxygen-carrying capacity (1%)
- C. Increased tissue oxygen extraction (1%)
- D. Primary diffusion impairment (5%)
- ✓ E. Ventilation/perfusion mismatch (85%)

Omitted
Correct answer
E

85%
Answered correctly

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06/21/2020
Last Updated

Explanation

Pulmonary embolism

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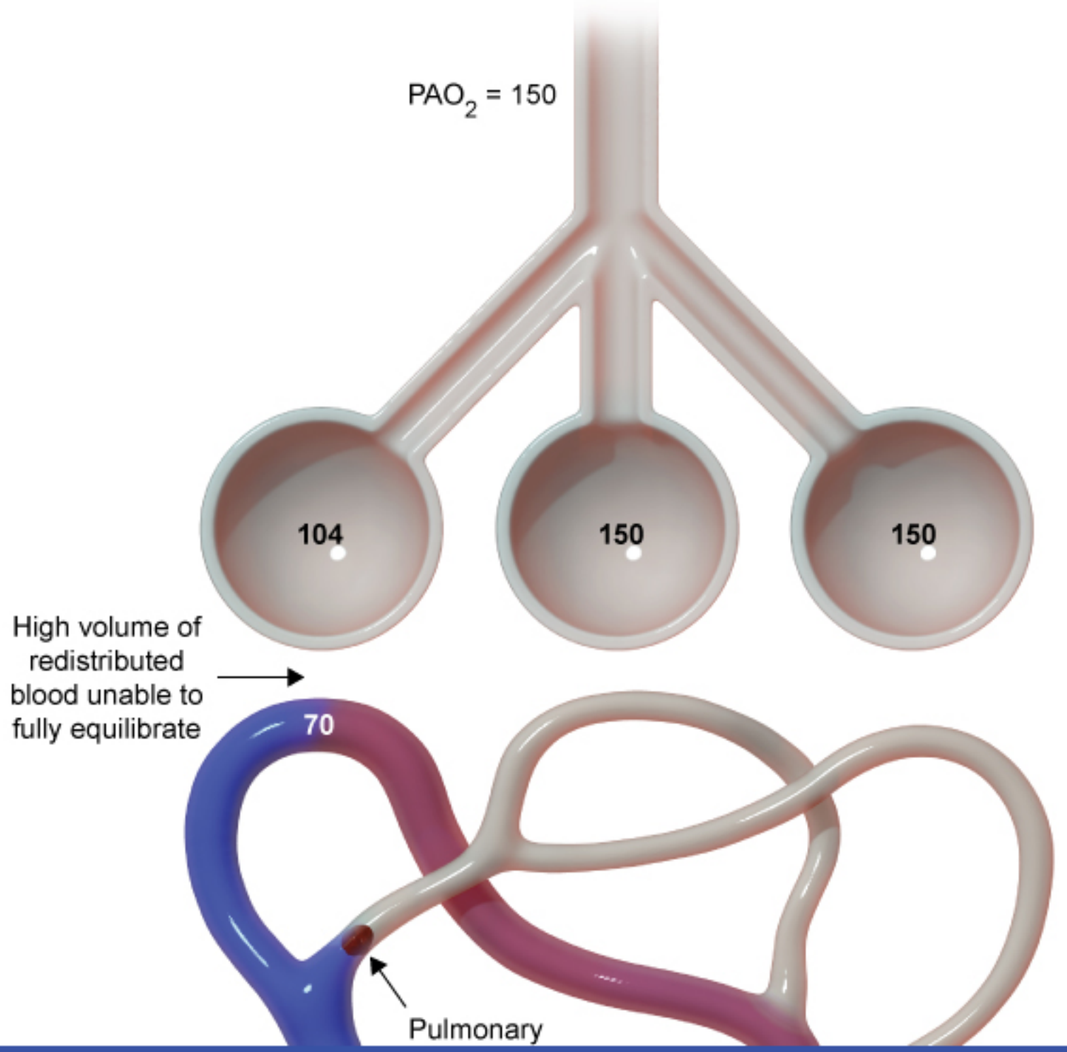
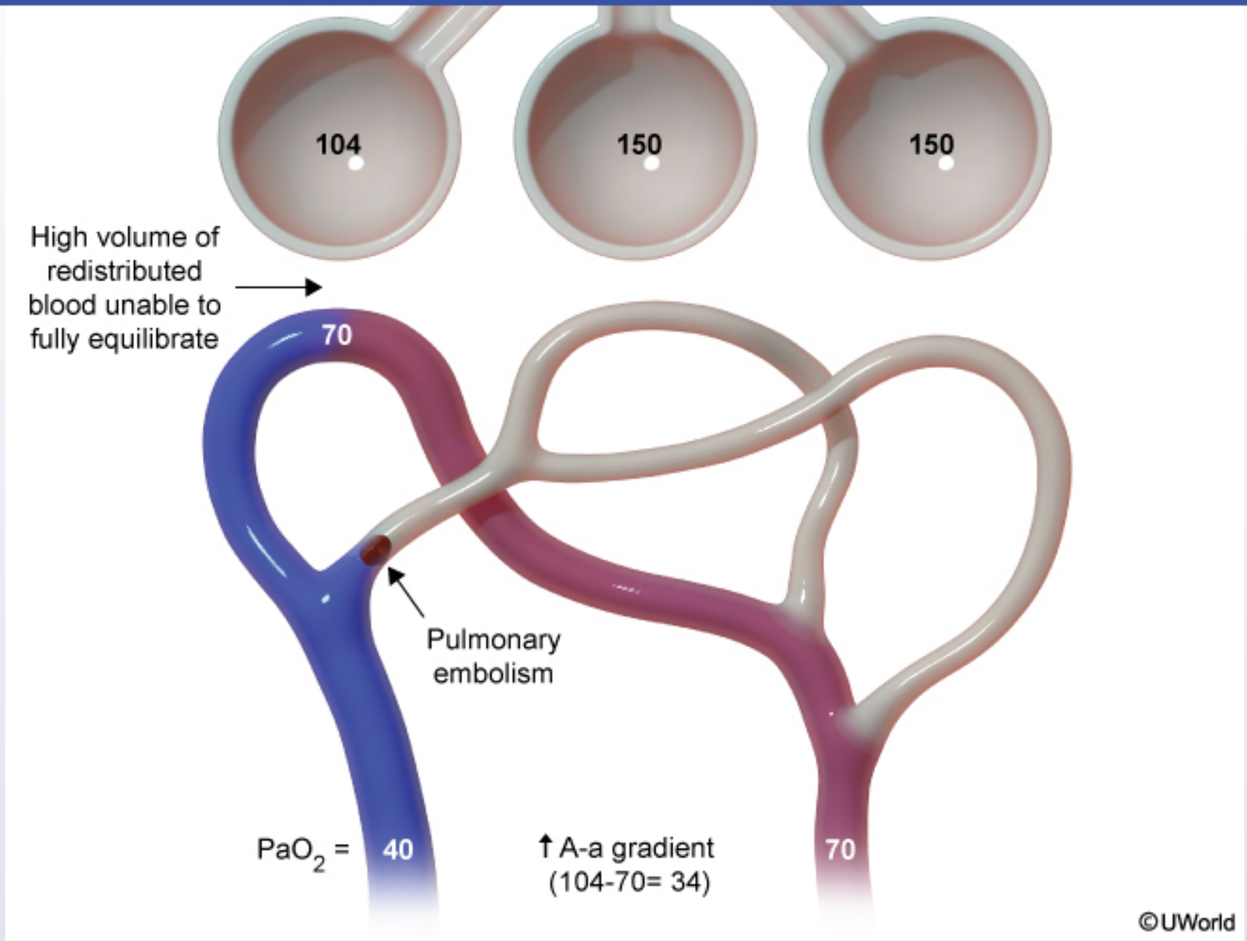
Pulmonary embolism





Sudden-onset shortness of breath and chest pain in a hospitalized patient should raise suspicion for **pulmonary embolism** (PE). This patient has 2 important risk factors for PE: **Immobilization** (causes venous stasis) and **recent surgery** (inflammation induces a hypercoagulable state). The risk of PE is high after large orthopedic procedures; prophylactic anticoagulation reduces but does not eliminate this risk. Thrombi most commonly originate in the deep veins of the pelvis and lower extremities before embolizing to the lungs. Although the risk of fat embolism is also increased following a long-bone fracture, this patient lacks the typical skin rash and neurologic findings (eg, confusion).

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Sudden chest shortness of breath and chest pain in a hospitalized patient should raise suspicion for **pulmonary embolism** (PE). This patient has 2 important risk factors for PE: **Immobilization** (causes venous stasis) and **recent surgery** (inflammation induces a hypercoagulable state). The risk of PE is high after large orthopedic procedures; prophylactic anticoagulation reduces but does not eliminate this risk. Thrombi most commonly originate in the deep veins of the pelvis and lower extremities before embolizing to the lungs. Although the risk of fat embolism is also increased following a long-bone fracture, this patient lacks the typical skin rash and neurologic findings (eg, confusion).

Thrombotic occlusion of the pulmonary circulation leads to redistribution of blood flow in the lungs, resulting in a **ventilation/perfusion (V/Q) mismatch**. With many well-ventilated alveoli now inaccessible to blood flow (dead-space ventilation), the remaining accessible alveoli are unable to fully oxygenate the volume of blood that continues to flow through the pulmonary circulation, and **hypoxemia** results. As with any V/Q mismatch that affects only part of the lungs, supplemental oxygen can help correct the hypoxemia by increasing the alveolar partial pressure of oxygen, allowing accessible alveoli to transfer additional oxygen to the blood.

(Choice A) Alveolar hypoventilation refers to a global decrease in the alveolar partial pressure of oxygen caused by a decrease in tidal volume or respiratory rate. Patients also develop respiratory acidosis due to decreased CO_2 excretion. This patient's respiratory alkalosis is more typical of V/Q mismatch with subsequent hyperventilation, as V/Q mismatch does not hinder CO_2 removal as much as blood oxygenation.

(Choice B) Decreased blood oxygen-carrying capacity (ie, decreased hemoglobin concentration) can occur due to postoperative bleeding. Although a decrease in hemoglobin can lead to tissue hypoxia, the measured PaO_2 (indicative of dissolved oxygen content rather than hemoglobin-bound oxygen content) will not be affected.

(Choice C) Increased tissue oxygen extraction would cause venous oxygen levels to decrease but would not typically affect the arterial oxygen content.

(Choice D) Hypoxemia due to a primary defect that impairs gas diffusion between the alveoli and pulmonary capillaries can occur in chronic lung diseases, including pulmonary fibrosis and emphysema.

Educational objective:
Pulmonary embolism is common in hospitalized and postoperative patients, and classically presents with sudden-onset shortness of breath and pleuritic chest pain. It causes hypoxemia due to ventilation/perfusion mismatch; arterial PCO_2 is usually normal or decreased.

Physiology Pulmonary & Critical Care Pulmonary embolism

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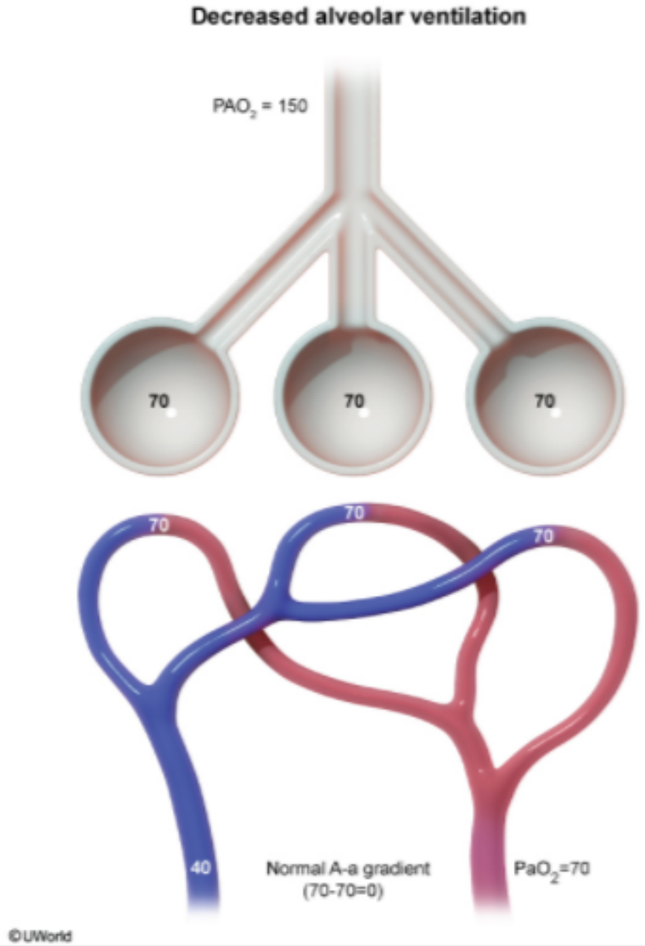

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Physiology | Pulmonary & Critical Care | Pulmonary embolism

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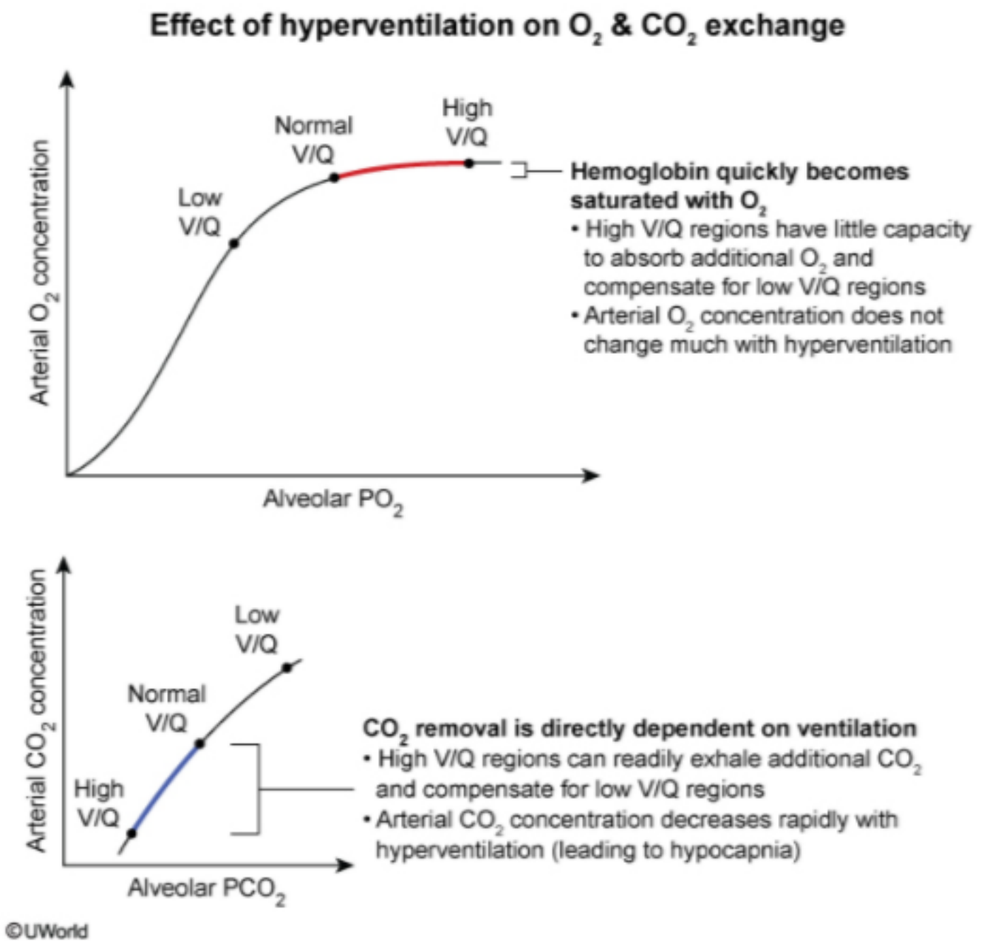

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Physiology Pulmonary & Critical Care Pulmonary embolism

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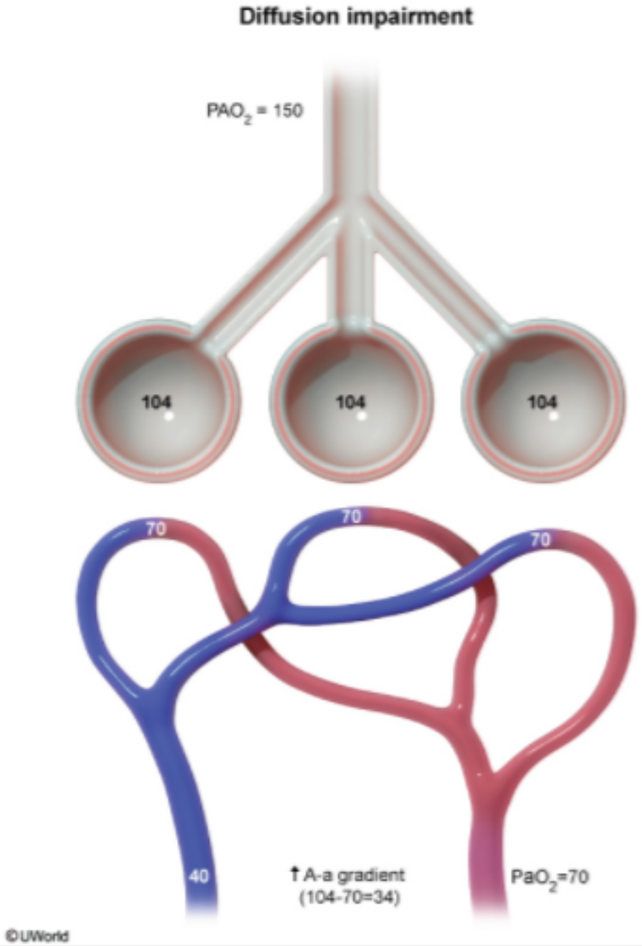

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Physiology | Pulmonary & Critical Care | Pulmonary embolism